CREATION OF A WHOLE-CORE PWR BENCHMARK FOR THE ANALYSIS AND VALIDATION OF NEUTRONICS CODES

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CREATION OF A WHOLE-CORE PWR BENCHMARK FOR THE ANALYSIS AND VALIDATION OF NEUTRONICS CODES

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LIST OF SYMBOLS AND ABBREVIATIONS

F_i	Normalized fission density in node i
e_{Fi}	Uncertainty of the normalized fission density in node i
PF_i	The ratio of peak to average fission density in node i
e_{PFi}	The uncertainty of the ratio of peak to average fission density in node i
$f_{k,i}$	The fission density of pin k in node i
$e_{k,i}$	The uncertainty associated with the fission density of pin k in node i
$f_{m,i}$	The maximum fission density in node i
$e_{m,i}$	The uncertainty associated with the maximum fission density in node i
$F_{k,i}$	The normalized fission density of pin k in node i
PWR	Pressurized water reactor
ARI	All-rods-in
ARO	All-rods-out
SRI	Some-rods-in
CLT	Coolant
TRU	Trans-uranic
UO_2	Uranium dioxide
MOX	Mixed oxide
TP	Top plug
BP	Bottom plug
TS	Tube/Spring
C1, C2, C3, C4	Core levels form 1 lowest to 4 highest

SUMMARY

This work presents a whole-core benchmark problem based on a 2-loop pressurized water reactor with both UO_2 and MOX fuel assemblies. The specification includes heterogeneity at both the assembly and core level. The geometry and material compositions are fully described and multi-group cross section libraries are provided in 2, 4, and 8 group formats. Simplifications made to the benchmark specification include a Cartesian boundary, to facilitate the use of transport codes that may have trouble with cylindrical boundaries, and control rod homogenization, to reduce the geometric complexity of the problem. These modifications were carefully chosen to preserve the physics of the problem and a justification of these modifications is given. Detailed Monte Carlo reference solutions including core eigenvalue, assembly averaged fission densities and selected fuel pin fission densities are presented for benchmarking diffusion and transport methods. Three different core configurations are presented in the paper namely all-rods-out, all-rods-in, and some-rods-in.

CHAPTER 1

INTRODUCTION

As new computer codes are developed for solving the transport equation in reactor problems, it is essential for methods developers to have at their disposal effective and robust computational benchmarks. In order to validate computational methods and reactor codes that may be used for real-world reactor problems, the benchmark configurations must be representative of realistic reactors, which implies that they must be large-scale 3-dimensional models that are highly heterogeneous both at the assembly and the core levels.

Until recent years, benchmark problems have been kept relatively simple composed of only a small number of assemblies (see references 1 and 2 for examples). In addition, the complexity of reactor systems often requires a significant amount of homogenization in order to make the core-level problem tractable for computer systems. The dramatic increase in computational power together with the advancements in solution methods have allowed for an increase in the complexity of problems that can be solved. While some large scale benchmarks exist, see references 3, 4, 5, 6, and 7 as a non-exhaustive list of examples, the availability of whole-core benchmark problems typical of operating reactors in terms of heterogeneity and size in the literature are too few. The present work is a step to fill this gap in the literature by providing full-core heterogeneous benchmark problem descriptions to test the capabilities of new and existing methods for solving reactor problems. In this paper, a stylized 3-dimensional pressurized water reactor benchmark problem with UO_2 and MOX fuel is developed in three configurations; namely, All-Rods-Out (ARO), All-Rods-In (ARI), and Some-Rods-In (SRI).

The benchmark specification includes multi-group material cross sections for consistent detailed whole-core calculations. Isotopic number densities are also provided

to enable continuous energy whole-core calculations as well as enable readers to generate their own cross sections. In this paper these number densities were used to generate 2, 4, 8, and 47 group cross section libraries using the lattice depletion transport code HELIOS Version 1.8 [8]. Reference solutions including core eigenvalue, assembly region averaged and fuel pin fission-density distributions were generated using the Monte Carlo code MCNP5[9] with the 8 group cross section library mentioned above. The pin fission densities are only presented for selected assemblies due to space limitations. The core eigenvalues are also presented for the 2, 4, 8, and 47 group libraries. Finally, studies into the use of a Cartesian boundary and control rod homogenization are presented in order to justify simplifications made to the benchmark specification.

CHAPTER 2

CORE SPECIFICATION

The benchmark specification is composed of square assemblies, laid out in a manner consistent with small pressurized water reactors. The layout of this specification is based upon a 2-loop Westinghouse PWR design [10]. The number of assemblies, overall core geometry, and location of control assemblies are used from this design, but types of assemblies and assembly dimensions are modified. The intent of this problem is to create a mixed core (UO_2 and MOX) which is generally more challenging to methods than pure UO_2 cores. PWR designs make use of several different enrichments of UO_2 assemblies; however, in this benchmark problem only one type of UO_2 assembly was used in order to simplify the problem due to the addition of MOX assemblies. These MOX assemblies were laid out in a checkerboard pattern throughout the core.

Radial Layout

The core is composed of 121 square fuel assemblies laid out in a checkerboard pattern as shown in Figure 1. Reactivity control is maintained in the core by control rod banks in the assemblies marked S (shutdown), A, B, C, D, which are removed from the core in that order. Bank D is used for power shaping, and is the only bank partially inserted in the core during full-power operation. There is also a Partial Length (PL) control bank, which extends over the bottom 75% of the axial length of the core.

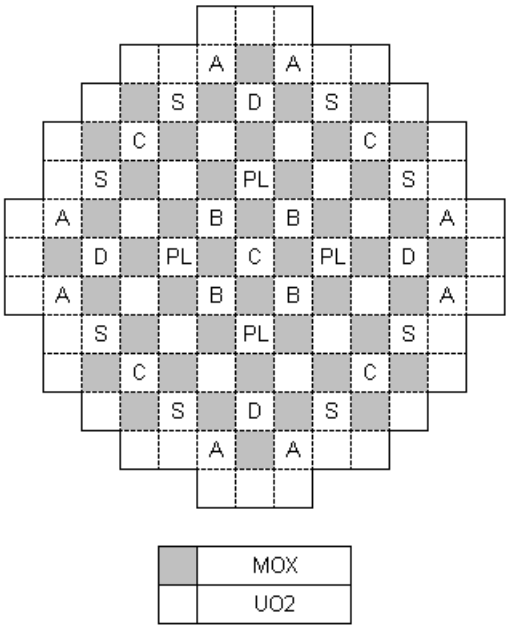


Figure 1. Radial core layout with locations of control banks

Due to the presence of control rod banks in several assemblies, there are 3 possible assembly types in this PWR problem: Uncontrolled UO_2 (UO_2), Controlled UO_2 (UO_2-C) and Uncontrolled MOX (MOX). There are no core configurations with controlled MOX assemblies.

The specific power (34.8 W/g) and the moderator temperature (576 K) for the core were chosen to be representative of the 2-Loop PWR design [10]. The boron concentration in the moderator was chosen as such in order to obtain a value close to criticality for the SRI configuration. All other state parameters for the benchmark specification are based on the OECD/NEA PWR core transient benchmark[3]. State parameters for the PWR problem are presented in Table I.

TABLE 1. State parameters.

Number of Fuel Assemblies	121
Specific Power Level	34.8 W/g
Fuel Temperature	900 K
Structure Temperature	600 K
Moderator Temperature	576 K
Assembly Pitch	21.42 cm

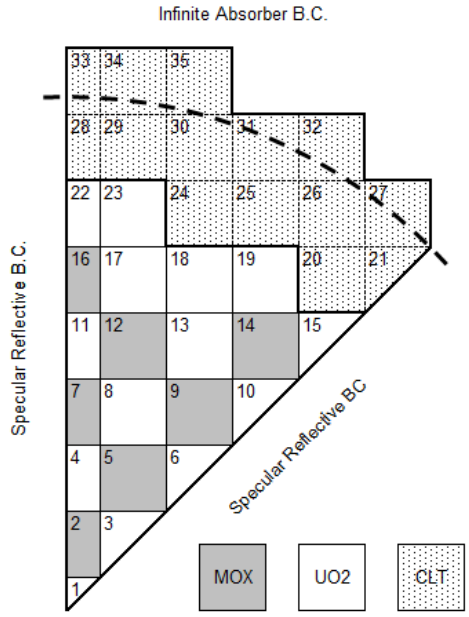


Figure 2. 1/8th symmetry layout with assembly indices, dashed line represents the position of the core barrel

The core layout is simplified by implementation of 1/8th symmetry in the radial layout, as depicted in Figure 2. Assemblies shaded as coolant in Figure 2 are composed of the same moderator material as in the uncontrolled UO_2 assemblies. The surrounding coolant boundary was specified with square assemblies in order to facilitate Cartesian transport codes while maintaining a shape close to that of the core barrel of the reactor. In

Figure 2 the core barrel is represented with a dashed line and has a radius of 168.15 cm if one wishes to model the coolant boundary exactly. In the reference calculations, specular reflective boundary conditions were used along the symmetry boundaries. For simplicity, reentrant particles are not treated; an infinite absorber boundary condition was used at the top, bottom, and radial external boundaries.

Axial Layout

The axial layout of the core is based on the Westinghouse design [10], and is composed of seven regions: a bottom plug (BP), 4 core layers (C1, C2, C3, and C4), tube/spring (TS), and a top plug (TP). This is laid out as in Figure 3.

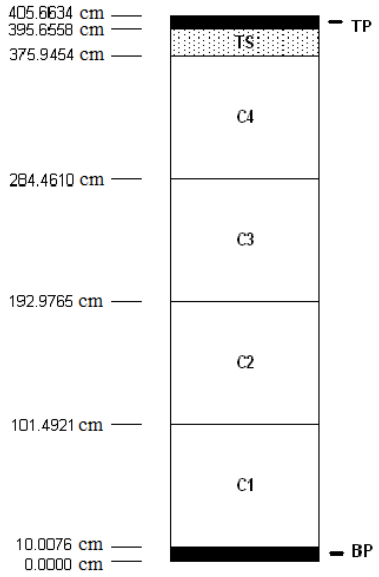


Figure 3. Axial core layout

The individual core layers all share the same radial layout except for variation in the control rod banks. Including axial variation, the core is divided into 847 nodes (121 fuel assemblies * 7 axial layers), composed of 6 different types of assembly, shown in

Table 2. The detailed geometry and composition of the assemblies are described in chapter 3.

TABLE 2. Assembly types

Assembly Number	Assembly Type
1	UO_2 – Controlled
2	UO_2 – Uncontrolled
3	MOX – Uncontrolled
4	Tube / Spring – Uncontrolled
5	Tube / Spring – Controlled
6	Plug

Core Configurations

Three configurations are described in this paper: all-rods-out (ARO), all-rods-in (ARI), and some-rods-in (SRI). The ARI configuration consists of all control banks fully inserted. The ARO configuration has all control banks fully withdrawn. The SRI Configuration includes the partial length bank fully inserted, control bank D halfway inserted and all other banks fully withdrawn. All assemblies that include control banks in the withdrawn or partially withdrawn position include control rods in the tube/spring axial layer. These configurations are depicted in Tables 3-5.

TABLE 3. All-Rods-Out configuration: assembly indices are horizontal, axis layers are vertical, and shaded regions represent controlled assemblies

ARO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	22	23
TP	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
TS	5	4	5	5	4	4	4	4	4	5	5	4	5	4	4	4	5	4	4	4	4
C4	2	3	2	2	3	2	3	2	3	2	2	3	2	3	2	3	2	2	2	2	2
C3	2	3	2	2	3	2	3	2	3	2	2	3	2	3	2	3	2	2	2	2	2
C2	2	3	2	2	3	2	3	2	3	2	2	3	2	3	2	3	2	2	2	2	2
C1	2	3	2	2	3	2	3	2	3	2	2	3	2	3	2	3	2	2	2	2	2
BP	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

TABLE 4. All-Rods-In configuration assembly types: assembly indices are horizontal, axis layers are vertical, and shaded regions represent controlled assemblies

ARI	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	22	23
TP	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
TS	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
C4	1	3	1	2	3	2	3	2	3	1	1	3	1	3	2	3	1	2	2	2	2
C3	1	3	1	1	3	2	3	2	3	1	1	3	1	3	2	3	1	2	2	2	2
C2	1	3	1	1	3	2	3	2	3	1	1	3	1	3	2	3	1	2	2	2	2
C1	1	3	1	1	3	2	3	2	3	1	1	3	1	3	2	3	1	2	2	2	2
BP	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

TABLE 5. Some-Rods-In configuration assembly types: assembly indices are horizontal, axis layers are vertical, and shaded regions represent controlled assemblies

SRI	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	22	23
TP	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
TS	5	4	5	4	4	4	4	4	4	5	5	4	5	4	4	4	5	4	4	4	4
C4	2	3	2	2	3	2	3	2	3	2	1	3	2	3	2	3	2	2	2	2	2
C3	2	3	2	1	3	2	3	2	3	2	1	3	2	3	2	3	2	2	2	2	2
C2	2	3	2	1	3	2	3	2	3	2	2	3	2	3	2	3	2	2	2	2	2
C1	2	3	2	1	3	2	3	2	3	2	2	3	2	3	2	3	2	2	2	2	2
BP	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

CHAPTER 3

ASSEMBLY SPECIFICATIONS

Both types of assembly (UO_2 and MOX) used in this problem are based on the assemblies used in the NEA C5G7 model[1,2]; however, that design generated homogenized cross-sections for each square pin cell. In order to test codes for whole core transport, spatial homogenization is not necessarily desired. Thus, in the current specification, each pin cell is composed of a square, 1.26 cm in width, filled with moderator. Centered in the pin cell is a circular pin of fuel, surrounded by zirconium cladding. Each assembly consists of a 17x17 square lattice of pin cells, with 24 guide tubes/control rods evenly spaced throughout, and one central guide tube.

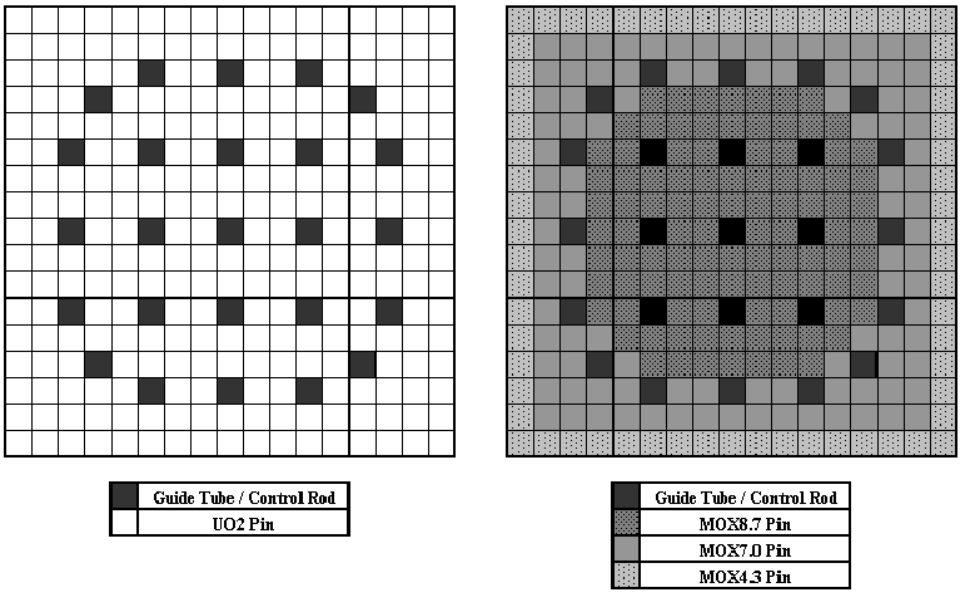


Figure 4. PWR fuel assemblies (UO2 left, MOX right)

The UO_2 assemblies consist of a single type of fuel pin, but the MOX assemblies consist of 3 different trans-uranic (TRU) enrichments of MOX fuel pins (8.7%, 7.0%, and 4.3% by weight TRU). In the uncontrolled assemblies, the non-central guide tubes are

composed of an annular region of zirconium filled with moderator. For the controlled assemblies, control rods have been simplified as an inner region of control material surrounded by an annular region of homogenized clad and moderator. To simulate the effects of a fission chamber in the central guide tube, a small amount of U-235 is added to the moderator[2]. The assemblies are depicted in Figure 4.

Material compositions for each region are in Appendix A. Geometric parameters for the fuel assemblies are presented in Table 6. The geometric parameters in Table 6 are taken from reference 2 except for the guide tube specifications which are from reference 11.

TABLE 6. Fuel assembly parameters

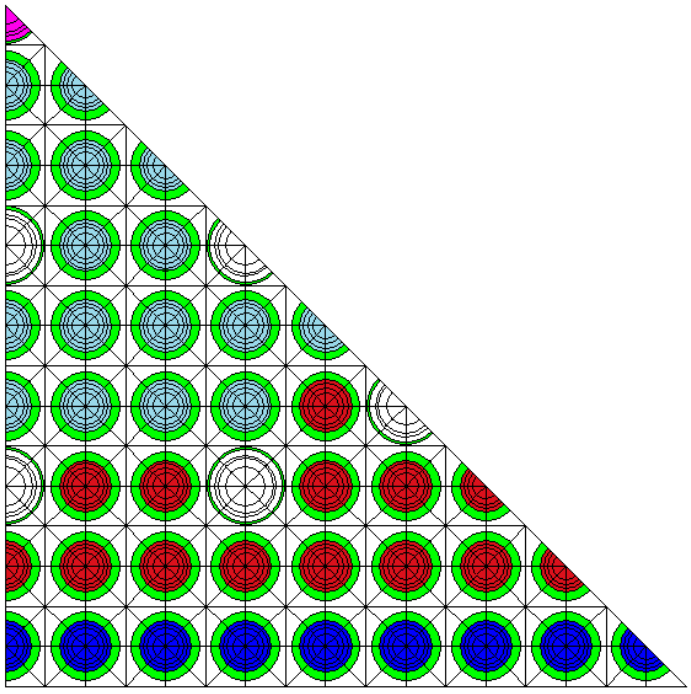
Number of Fuel Pins / Assembly	264
Number of Control Rods / Guide Tubes	24
Fuel Pin Radius	0.4095 cm
Fuel Pin Clad Radius	0.54 cm
Control Radius	0.4331 cm
Guide Tube Inner Radius	0.573 cm
Guide Tube / Control Rod Outer Radius	0.613 cm
Pin Pitch	1.26 cm

The Tube/Spring axial layer is composed of geometry identical to the fuel assemblies, where the fuel material has been replaced with zirconium cladding material. The other materials in the controlled and uncontrolled tube/spring assemblies are the same materials as the controlled and uncontrolled UO_2 assemblies, respectively. The plug assembly materials are the same as the uncontrolled UO_2 assemblies, but both the guide tube and fuel regions are replaced with zirconium cladding material.

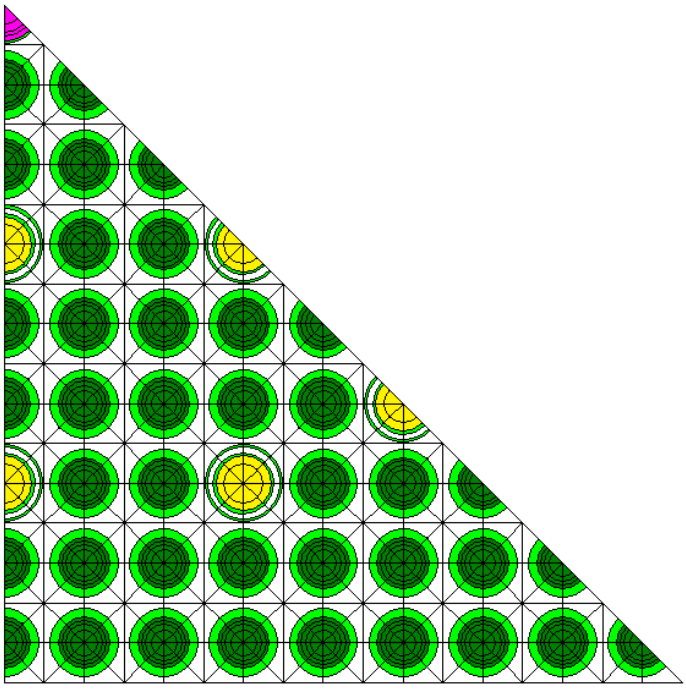
CHAPTER 4

CROSS SECTION LIBRARY GENERATION

Multi-group material cross sections were generated using the lattice depletion transport code HELIOS. The 47-group production library was used to perform single assembly lattice depletion calculations in both UO_2 and MOX assemblies with and without control rods, using full specular reflective boundary conditions. These calculations were used to generate 47 group as well as condensed (flux weighted) 2, 4 and 8 group cross sections for each material region. Cross sections were generated for each unique material, averaged by flux weighting, in order to simplify the problem while retaining its physics. The non-fuel cross sections from the UO_2 assemblies are used for the plug and tube/spring assemblies. The HELIOS computational models, taking advantage of the $1/8^{th}$ symmetry are shown in Figure 5.



(a)



(b)

Figure 5. HELIOS cross-section generation models:
MOX (a) and UO_2-C (b)

As shown in Figure 5 (b), for cross section generation the control rods are modeled explicitly. The control rod is centered within the guide tube and has a control clad radius of 0.4839 cm and a control radius of 0.4331 cm^3. The gap between the control clad and guide tube clad is filled with moderator. The cross sections for the control clad, guided tube clad, and the moderator in the gap of the guide tube was then homogenized (flux weighted) into one cross section region. This was done to simplify the number of cross sections needed to describe the problem while maintaining its physics. As also seen in figure 6, the spatial mesh used during the transport calculation was obtained by dividing each fuel pin into 4 equal area annular regions and 8 equal angle azimuthal segments. The cladding material, as well as the gap between the guide tube and the control rod, was split into 8 equal angle azimuthal regions. The control material was split into two equal area annular regions and 8 azimuthal segments and the moderator in each pin cell area was divided into 8 equal area regions. The transport calculation was used to

generate 47 group material cross sections which were then collapsed into the 2, 4, and 8-group structure in Table 7, using HELIOS with the criticality spectrum option on, and equilibrium xenon and samarium concentrations. The cross sections for the group structures in Table 7 are presented in Appendices B, C, and D using a computer-accessible format.

TABLE 7. Energy group structure

2-Group	4-Group	8-Group	Lower Energy Bound (eV)
1	1	1	2.2313E+06
		2	8.2085E+05
		3	9.1188E+03
	2	4	1.3007E+02
		5	3.9279E+00
	3	6	6.2506E-01
2	4	7	1.4572E-01
		8	1.0000E-04

CHAPTER 5

BOUNDARY INVESTIGATION

For this benchmark problem a Cartesian boundary was chosen in order to facilitate the use of transport codes that may have troubles with cylindrical boundaries. The Cartesian boundary was chosen to approximate the curvature of the core barrel as closely as possible while retaining assembly sized coolant regions. The Cartesian boundary along with a superposition of the core barrel location is shown in Figure 2.

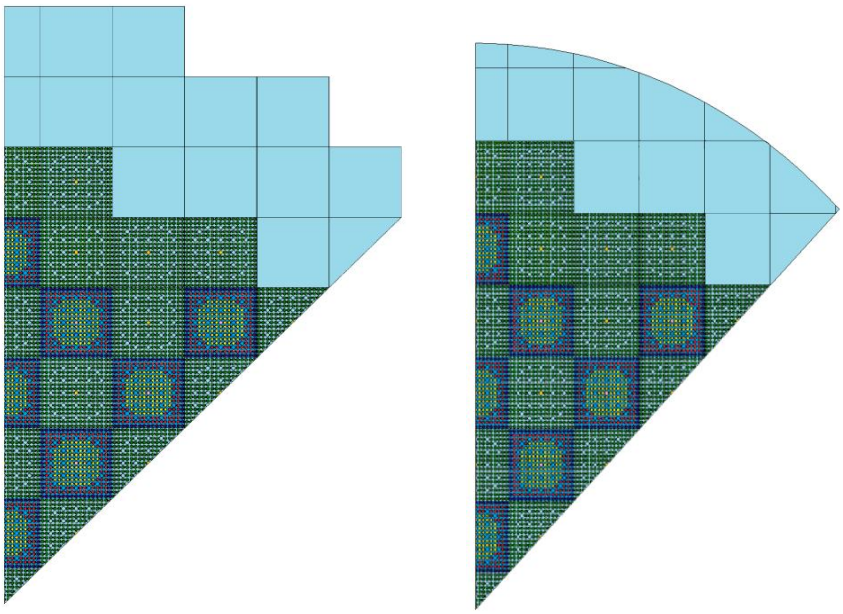


Figure 6. Continuous energy MCNP5 models with a Cartesian boundary (a) and a cylindrical boundary (b)

The two different boundaries were modeled in MCNP5 in order to test the effect of using a non-realistic Cartesian boundary instead of a cylindrical boundary. As seen in Figure 6, MCNP5 model (a) represents the boundary as presented in this benchmark specification while model (b) has a boundary correlating to the position of the core barrel

in the Westinghouse PWR design. The material compositions for these models are those specified in Appendix A. Continuous energy cross sections at 300K, provided with MCNP5, were used for the core calculations. Both boundary conditions were simulated in MCNP5 for ARI, ARO, and SRI configurations with 3E9 neutron histories (1.5E9 for source convergence). Table 8 shows the result of these calculations.

TABLE 8. Eigenvalue results (and uncertainty) for the Cartesian and cylindrical continuous energy MCNP5 models for the ARO, ARI and SRI core configurations

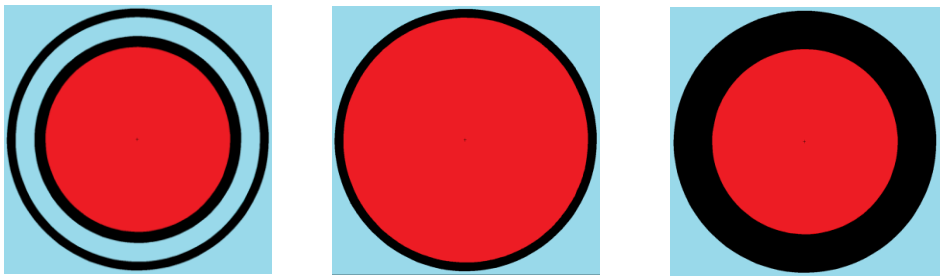
	ARO	ARI	SRI
Cartesian	1.06457 (0.00002)	0.97787 (0.00002)	1.04134 (0.00002)
Cylindrical	1.06457 (0.00002)	0.97787 (0.00002)	1.04135 (0.00002)
Difference	0 (0.000028)	0 (0.000028)	-0.00001 (0.000028)

The eigenvalue results for both the core configurations presented were statistically similar. As seen in Table 8, the results of the core eigenvalue only change for the SRI configuration and only by 1 pcm. When comparing pin fission density results on the perimeter similar results are found with little difference in fission densities between the two different boundary representations. It can be concluded that for this specific benchmark problem, the use of an appropriate Cartesian boundary is appropriate because it has no statistically notable effect on core eigenvalue and fission density results.

CHAPTER 6

HOMOGENIZATION SCHEME INVESTIGATION

In this benchmark specification control rods are simplified to be composed of only two radial regions. To try and quantify the effect that this simplification has on the physics of the benchmark specification a parametric study was performed on the assembly level. A controlled UO2 assembly was first modeled in HELIOS with full specular reflective boundaries and with discrete control rod representation as shown in figure 5 (b). This model, using the HELIOS 47 group library and the material densities in Appendix A, was used to calculate the eigenvalue for the reflected control assembly. This model was also then to generate three different sets of 47 group cross sections for different homogenization schemes.



(a) (b) (c)

Figure 7. Pin cell homogenization schemes: (a) Distinct control rod representation, (b) Homogenization of area inside the guide tube clad, and (c) Homogenization of region outside of the control material

The first set has unique cross sections for each material type namely fuel, cladding, moderator, control, and central guide tube moderator effectively keeping the control rods explicitly modeled as in Figure 7 (a). For the second cross section set the control material was homogenized with the surrounding control cladding and guide tube gap moderator by flux weighting creating the control rod approximation as seen in Figure

7 (c). The last cross section set homogenized the guide tube cladding, guide tube gap moderator, and control rod cladding by flux weighing and left the control material untouched as seen in Figure 7 (c).

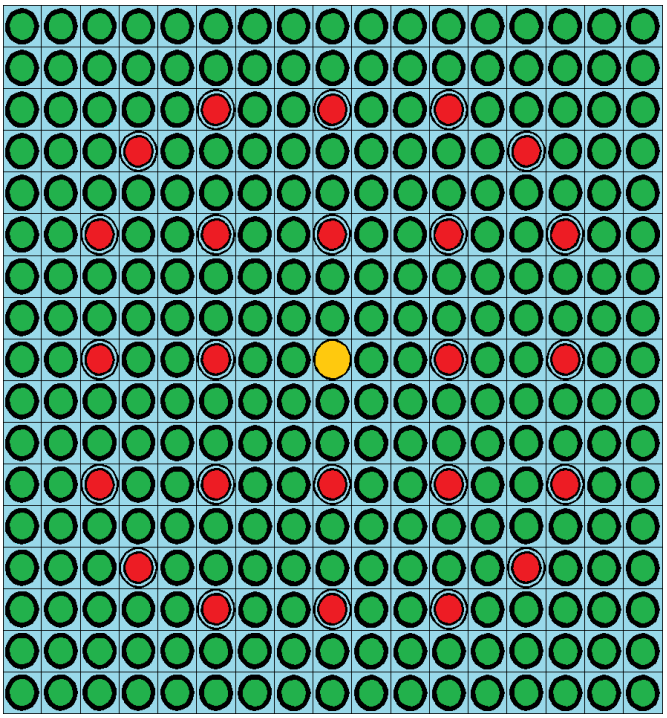


Figure 8. MCNP5 assembly model for the discrete control rod representation

Eigenvalue results for the controlled UO2 assembly were then generated using MCNP5 with the three separate homogenization schemes. A figure of the MCNP5 assembly model using the control rod representation in Figure 7 (a) is shown in Figure 8. The eigenvalue results for each of the homogenization schemes along with their difference from the HELIOS lattice calculation eigenvalue can be found in Table 9.

TABLE 9. Eigenvalue results for a controlled UO2 assembly using different homogenization schemes

Case	Eigenvalue (uncertainty)	Difference
HELIOS 47 group calculation	0.68287	-
No Homogenization (a)	0.69119 (0.00008)	0.00832
Inside Homogenization (b)	0.65498 (0.00007)	-0.02789
Outside Homogenization (c)	0.67713 (0.00007)	-0.01406

In Table 9 the HELIOS 47 group calculation represents the reference solution since cross sections have not yet been simplified from the HELIOS master 47 group library. As seen from Table 9, the case with no homogenization and one unique cross section for each material gives the least difference from the reference solution while the homogenization of control material into the gap (inside homogenization) leads to the greatest error. The outside homogenization case where the control material was left alone and the regions outside control were homogenized gave an error greater than the no homogenization but much less than the no homogenization. The inside homogenization case is inaccurate because control material is spread out over a larger area decreasing the effect that self-shielding had on the smaller control region. While not perfect, outside homogenization was chosen for the specification since the geometric model is simpler than the no homogenization case while being only 600 pcm farther away from the reference solution.

CHAPTER 7

REFERENCE SOLUTION

The benchmark problem for each configuration (ARI, ARO, and SRI) was modeled with MCNP5, using the 2, 4, 8, and 47 group libraries produced from the HELIOS transport calculation and the MCNP multi-group option. The boundary conditions used are found in section 2.1. The problem was modeled in full heterogeneity, as shown in Figure 7.

The problem was run on a 160-core computer cluster with 3.0E9 neutron histories (1.5E9 for source convergence), using the multi-group option and the 4 sets of multi-group cross sections mentioned previously. For each configuration a converged source was created by simulating 250,000 particles with 6000 cycles. Using this converged source, the three configurations were simulated with 250,000 particles in each cycle, with 6000 cycles (400 inactive). Fission density was tallied in all fission producing fuel pins for each core layer (C1-C4) and all tallies passed the MCNP statistical checks. The core eigenvalues for the three configurations considered are found in Table 10.

TABLE 10. Configuration eigenvalues and (standard deviation)

	ARO	ARI	SRI
2 g	1.02630 (0.00001)	0.95111 (0.00001)	1.00664 (0.00001)
4 g	1.02226 (0.00001)	0.94485 (0.00001)	1.00177 (0.00001)
8 g	1.01991 (0.00001)	0.93869 (0.00001)	0.99833 (0.00001)
47 g	1.01888 (0.00001)	0.93637 (0.00001)	0.99695 (0.00001)

The fuel node averaged fission distribution and peaking factors are presented for the 8-group calculation. Due to the large number of fuel pins present in the core, fuel pin

fission densities are presented only for a select number of assemblies. The fuel node averaged fission density distributions for the ARO, ARI, and SRI configurations are found in Tables 11, 12, and 13, respectively. The corresponding one standard deviation relative percent uncertainties are found in Tables 14, 15, and 16. The shaded cells in these tables indicate controlled regions and assembly indices in these tables can be found in Figure 2.

TABLE 11. Average normalized pin fission density, configuration: ARO

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
C4	1.3089	1.3356	1.2177	1.1340	1.1549	0.9711	0.9905	0.8981	0.8257	0.6031	
C3	2.7976	2.8501	2.6072	2.4244	2.4610	2.0707	2.1078	1.9121	1.7577	1.2886	
C2	2.7885	2.8417	2.5998	2.4184	2.4550	2.0671	2.1033	1.9094	1.7548	1.2872	
C1	1.3074	1.3321	1.2187	1.1331	1.1523	0.9688	0.9874	0.8950	0.8228	0.6021	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	0.6898	0.6907	0.5566	0.4092	0.2105	0.4511	0.3998	0.3192	0.1832	0.1958	0.1685
C3	1.4701	1.4689	1.1879	0.8722	0.4485	0.9588	0.8524	0.6798	0.3902	0.4168	0.3585
C2	1.4707	1.4677	1.1869	0.8712	0.4483	0.9590	0.8522	0.6788	0.3895	0.4171	0.3578
C1	0.6879	0.6876	0.5553	0.4072	0.2093	0.4489	0.3984	0.3174	0.1822	0.1951	0.1673

TABLE 12. Average normalized pin fission density, configuration ARI

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
C4	1.5045	3.2806	2.0251	4.5243	4.6933	4.3490	4.2889	3.9907	3.2060	1.0201	
C3	0.9343	1.8527	1.2781	1.4801	3.1261	3.4243	2.8485	2.9989	2.6493	0.8939	
C2	0.3288	0.6533	0.4620	0.5252	1.1634	1.3126	1.0657	1.1422	1.0311	0.3553	
C1	0.0933	0.1854	0.1315	0.1495	0.3310	0.3728	0.3039	0.3254	0.2933	0.1014	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	1.1909	2.0789	0.8695	0.9469	0.5534	0.8403	0.4590	0.6156	0.4466	0.3757	0.2860
C3	0.9452	1.7068	0.7564	0.8805	0.5359	0.7446	0.4084	0.5702	0.4300	0.3574	0.2718
C2	0.3663	0.6655	0.3005	0.3589	0.2219	0.2993	0.1643	0.2326	0.1779	0.1475	0.1122
C1	0.1040	0.1896	0.0858	0.1026	0.0634	0.0853	0.0469	0.0665	0.0509	0.0419	0.0321

TABLE 13. Average normalized pin fission density, configuration SRI

	1	2	3	4	5	6	7	8	9	10	
C4	2.0381	2.0514	1.8622	1.6366	1.7244	1.4882	1.2433	1.2360	1.2534	0.9545	
C3	2.2313	2.0801	1.9920	0.8934	1.8644	1.9182	1.3677	1.5606	1.7744	1.4539	
C2	1.9843	1.8723	1.8317	0.8599	1.8310	1.9328	1.6809	1.7505	1.8838	1.5361	
C1	1.0216	0.9683	0.9494	0.4536	0.9630	1.0172	0.9131	0.9393	0.9997	0.8126	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	0.3865	0.8103	0.8086	0.6502	0.3461	0.4296	0.4580	0.4432	0.2844	0.2168	0.1966
C3	0.5634	1.1964	1.2497	1.0295	0.5586	0.7161	0.7551	0.7225	0.4646	0.3775	0.3387
C2	1.5152	1.6001	1.4140	1.1110	0.5974	1.1339	1.0320	0.8585	0.5154	0.5299	0.4572
C1	0.8505	0.8789	0.7588	0.5908	0.3160	0.6378	0.5716	0.4648	0.2746	0.2967	0.2543

TABLE 14. Fission density uncertainty (% relative uncertainty), configuration: ARO

	1	2	3	4	5	6	7	8	9	10	
C4	0.0283	0.0185	0.0144	0.0148	0.0141	0.0160	0.0214	0.0117	0.0166	0.0203	
C3	0.0196	0.0127	0.0099	0.0101	0.0097	0.0110	0.0147	0.0081	0.0114	0.0140	
C2	0.0196	0.0128	0.0099	0.0102	0.0097	0.0111	0.0147	0.0081	0.0114	0.0140	
C1	0.0284	0.0185	0.0144	0.0148	0.0141	0.0161	0.0215	0.0118	0.0166	0.0203	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	0.0189	0.0181	0.0149	0.0235	0.0350	0.0317	0.0176	0.0199	0.0264	0.0360	0.0277
C3	0.0130	0.0125	0.0102	0.0161	0.0241	0.0218	0.0121	0.0137	0.0181	0.0247	0.0190
C2	0.0130	0.0125	0.0102	0.0161	0.0240	0.0218	0.0121	0.0137	0.0181	0.0247	0.0190
C1	0.0190	0.0181	0.0149	0.0235	0.0352	0.0317	0.0176	0.0200	0.0265	0.0361	0.0277

TABLE 15. Fission density uncertainty (% relative uncertainty), configuration: ARI

	1	2	3	4	5	6	7	8	9	10	
C4	0.0250	0.0124	0.0107	0.0079	0.0075	0.0082	0.0109	0.0061	0.0089	0.0149	
C3	0.0315	0.0163	0.0133	0.0123	0.0090	0.0092	0.0132	0.0069	0.0098	0.0158	
C2	0.0531	0.0274	0.0219	0.0205	0.0146	0.0145	0.0215	0.0109	0.0155	0.0250	
C1	0.0996	0.0513	0.0411	0.0384	0.0272	0.0271	0.0402	0.0202	0.0289	0.0468	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	0.0137	0.0110	0.0114	0.0162	0.0227	0.0242	0.0157	0.0150	0.0178	0.0272	0.0222
C3	0.0153	0.0121	0.0121	0.0167	0.0231	0.0257	0.0166	0.0156	0.0181	0.0279	0.0228
C2	0.0245	0.0192	0.0192	0.0261	0.0358	0.0404	0.0261	0.0243	0.0280	0.0433	0.0354
C1	0.0459	0.0359	0.0358	0.0488	0.0669	0.0757	0.0488	0.0454	0.0524	0.0815	0.0661

TABLE 16. Fission density uncertainty (% relative uncertainty), configuration: SRI

	1	2	3	4	5	6	7	8	9	10	
C4	0.0230	0.0151	0.0118	0.0125	0.0117	0.0131	0.0193	0.0101	0.0136	0.0164	
C3	0.0219	0.0150	0.0113	0.0153	0.0112	0.0116	0.0184	0.0090	0.0114	0.0133	
C2	0.0234	0.0157	0.0119	0.0155	0.0113	0.0116	0.0166	0.0085	0.0111	0.0130	
C1	0.0325	0.0218	0.0164	0.0213	0.0155	0.0158	0.0225	0.0116	0.0152	0.0178	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	0.0231	0.0169	0.0125	0.0189	0.0277	0.0327	0.0166	0.0171	0.0214	0.0346	0.0259
C3	0.0191	0.0139	0.0101	0.0150	0.0218	0.0253	0.0130	0.0134	0.0168	0.0263	0.0198
C2	0.0129	0.0121	0.0095	0.0145	0.0211	0.0202	0.0111	0.0124	0.0160	0.0222	0.0170
C1	0.0173	0.0162	0.0129	0.0198	0.0289	0.0269	0.0149	0.0167	0.0218	0.0296	0.0228

The normalized fuel node averaged fission densities presented in Tables 11-13 were produced using equation 1. In equation 1, the pin fission densities $f_{k,i}$ were summed over all the pins k in fuel node i, and then divided by the total fission density of the entire core (the summation of all the fission density tallies multiplied by 8 to account for the $1/8^{th}$ symmetry) and finally normalized to the number of fission producing nodes in the entire core (484; 121 assemblies * 4 axial fuel core layers). This normalization was done for all nodes accounting for partial assemblies and pins.

$$F_i = \frac{484 * \sum_k f_{k,i}}{8 * \sum_i \sum_k f_{k,i}} \quad (1)$$

The uncertainties of the normalized node fission densities were calculated using equation 2 where $f_{k,i}$ and $e_{k,i}$ represent the fission density and associated relative uncertainty for a fuel pin k in node i.

$$e_{F_i} = \sqrt{\left[\frac{\sqrt{\sum_k (e_{k,i} * f_{k,i})^2}}{\sum_k f_{k,i}}\right]^2 + \left[\frac{\sqrt{\sum_i \sum_k (e_{k,i} * f_{k,i})^2}}{\sum_i \sum_k f_{k,i}}\right]^2} \quad (2)$$

Because the reactor is composed of a very large number of fuel pins (31,944), presenting results for each pin is neither practical nor particularly instructive. It is often desired, however, to gain a measure of understanding of the peaking effect within a specific assembly. For this reason, the ratio of peak pin fission density to the average is presented for each node. The peak to average fission density was calculated by taking the maximum fission density in node i ($f_{m,i}$) and then dividing by the average fission density in that node. This calculation was done, accounting for partial pins and assemblies, using equation 3 where 264 is the number of fuel pins per node.

$$PF_i = \frac{f_{m,i}}{\sum_k f_{k,i}} * 264 \tag{3}$$

The relative uncertainty associated with the value of the peaking factor was calculated using equation 4 where $e_{m,i}$ is the uncertainty of the maximum fission density in node i.

$$e_{PF_i} = \sqrt{\left[e_{m,i}\right]^2 + \left[\frac{\sqrt{\sum_k (e_{k,i} * f_{k,i})^2}}{\sum_k f_{k,i}}\right]^2} \tag{4}$$

The peaking factors are presented in Tables 17-19 and the relative percent uncertainties associated with these numbers are presented in Tables 20-22.

TABLE 17. Peaking factors ARO

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
C4	1.1634	1.1400	1.1769	1.1819	1.1827	1.2188	1.2177	1.2257	1.2664	1.3120	
C3	1.1678	1.1421	1.1770	1.1844	1.1840	1.2197	1.2159	1.2274	1.2700	1.3130	
C2	1.1690	1.1394	1.1777	1.1836	1.1840	1.2183	1.2137	1.2299	1.2669	1.3136	
C1	1.1662	1.1400	1.1759	1.1866	1.1832	1.2202	1.2098	1.2265	1.2694	1.3136	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	1.2480	1.3094	1.3042	1.5155	1.5811	1.3993	1.3396	1.4617	1.6585	1.4248	1.6581
C3	1.2458	1.3071	1.3057	1.5216	1.5770	1.3898	1.3392	1.4650	1.6517	1.4222	1.6512
C2	1.2442	1.3113	1.3037	1.5126	1.5753	1.3926	1.3409	1.4647	1.6538	1.4263	1.6526
C1	1.2451	1.3086	1.3063	1.5162	1.5644	1.4037	1.3441	1.4587	1.6601	1.4208	1.6530

TABLE 18. Peaking factors ARI

	1	2	3	4	5	6	7	8	9	10	
C4	1.2014	1.3825	1.3989	1.1981	1.1952	1.2047	1.2776	1.2781	1.4902	2.0546	
C3	1.1996	1.2449	1.5942	1.3468	1.3018	1.1998	1.2225	1.2544	1.4453	1.9742	
C2	1.2065	1.2364	1.6449	1.3895	1.3275	1.2009	1.2196	1.2551	1.4338	1.9465	
C1	1.2073	1.2382	1.6262	1.3907	1.3306	1.1996	1.2152	1.2526	1.4374	1.9407	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	1.7281	1.6628	2.0622	1.5519	1.5070	1.4038	1.7298	1.4340	1.5355	1.4191	1.5385
C3	1.6596	1.6049	1.9639	1.4878	1.4972	1.3760	1.6835	1.4007	1.5255	1.4062	1.5303
C2	1.6395	1.5930	1.9260	1.4559	1.4825	1.3586	1.6672	1.3899	1.5152	1.3948	1.5145
C1	1.6410	1.5813	1.9099	1.4676	1.4862	1.3505	1.6888	1.3877	1.5356	1.3939	1.5145

TABLE 19. Peaking factors SRI

	1	2	3	4	5	6	7	8	9	10	
C4	1.1691	1.1494	1.1851	1.2007	1.1981	1.2205	1.3239	1.2458	1.2731	1.3020	
C3	1.1735	1.2184	1.1873	1.3207	1.2197	1.1759	1.2159	1.2438	1.2066	1.2671	
C2	1.1678	1.2079	1.1743	1.2631	1.2097	1.1748	1.1640	1.1861	1.1804	1.2592	
C1	1.1737	1.2066	1.1731	1.2473	1.2098	1.1698	1.1751	1.1796	1.1751	1.2529	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	1.5694	1.4202	1.2937	1.4967	1.5693	1.2302	1.3409	1.4450	1.6240	1.4030	1.6749
C3	1.4325	1.3596	1.2576	1.4558	1.5618	1.2179	1.3129	1.4283	1.6099	1.3985	1.6381
C2	1.1980	1.2153	1.2499	1.4502	1.5533	1.3296	1.2990	1.4320	1.6210	1.4093	1.6203
C1	1.1952	1.2033	1.2543	1.4503	1.5495	1.3363	1.3074	1.4288	1.6264	1.4158	1.6327

TABLE 20. Peaking factor percent relative uncertainties ARO

	1	2	3	4	5	6	7	8	9	10	
C4	0.2218	0.2108	0.1606	0.1607	0.2204	0.1807	0.2310	0.1804	0.2505	0.2209	
C3	0.1711	0.1406	0.1104	0.1503	0.1503	0.1205	0.1607	0.1203	0.1704	0.1506	
C2	0.1711	0.1406	0.1104	0.1105	0.1503	0.1205	0.1607	0.1203	0.1704	0.1506	
C1	0.2417	0.2108	0.1606	0.2205	0.2105	0.1807	0.3207	0.1804	0.2505	0.2209	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	0.2009	0.2606	0.2205	0.3109	0.3418	0.3216	0.2506	0.2707	0.3211	0.3518	0.3411
C3	0.1406	0.1804	0.1503	0.2106	0.2313	0.2211	0.1704	0.1805	0.2307	0.2413	0.2308
C2	0.1406	0.1804	0.1503	0.2106	0.2312	0.3108	0.1704	0.1805	0.2207	0.2413	0.2308
C1	0.2009	0.2606	0.2205	0.3109	0.3418	0.4511	0.2506	0.2707	0.3211	0.3518	0.3411

TABLE 21. Peaking factor percent relative uncertainties ARI

	1	2	3	4	5	6	7	8	9	10	
C4	0.1817	0.1704	0.1404	0.0903	0.1102	0.0904	0.1105	0.0902	0.1203	0.1607	
C3	0.2321	0.1807	0.1705	0.1206	0.1303	0.1004	0.1406	0.1002	0.1304	0.1807	
C2	0.3936	0.3012	0.2709	0.2010	0.2205	0.1606	0.2310	0.1604	0.2205	0.2911	
C1	0.7368	0.5623	0.5216	0.3720	0.4109	0.3112	0.4518	0.3007	0.4110	0.5420	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	0.1208	0.1404	0.1305	0.2106	0.2212	0.2512	0.1906	0.2006	0.2307	0.2714	0.2908
C3	0.1309	0.1604	0.1405	0.2206	0.2311	0.2712	0.2106	0.2106	0.2407	0.3810	0.3009
C2	0.2214	0.2507	0.2208	0.3510	0.3618	0.4219	0.3310	0.3409	0.3711	0.4322	0.4614
C1	0.4126	0.4813	0.4215	0.6518	0.6634	0.7638	0.6419	0.6316	0.7020	0.8240	0.8725

TABLE 22. Peaking factor percent relative uncertainties SRI

	1	2	3	4	5	6	7	8	9	10	
C4	0.2013	0.1707	0.1305	0.1306	0.1804	0.1506	0.2009	0.1503	0.2005	0.1807	
C3	0.1813	0.2205	0.1305	0.1508	0.1704	0.1305	0.2008	0.1303	0.1804	0.1506	
C2	0.2014	0.1707	0.1405	0.1607	0.1704	0.1305	0.1907	0.1303	0.1803	0.1406	
C1	0.2819	0.2410	0.1907	0.2210	0.2405	0.1807	0.2510	0.1804	0.2405	0.2008	
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**22**	**23**
C4	0.2113	0.2406	0.1804	0.2507	0.2615	0.3515	0.2406	0.2306	0.2708	0.3418	0.3410
C3	0.1810	0.2005	0.1503	0.2006	0.2111	0.2712	0.1904	0.1805	0.2107	0.2613	0.2607
C2	0.1406	0.1804	0.1403	0.1905	0.2011	0.2907	0.1604	0.1704	0.2006	0.2211	0.2107
C1	0.1908	0.2505	0.1904	0.2707	0.2815	0.2713	0.2105	0.2306	0.2709	0.2915	0.2809

Detailed pin fission density results are presented for the assembly regions with the highest normalized power peaking factors in each core configuration as well as a periphery assembly region for the SRI configuration. These selected results along with the assembly averaged fission densities in Tables 11-13 are intended to provide a way to validate new methods without having to generate benchmark results. The fission densities were normalized by dividing an individual pin segment fission density by the total fission density of the entire core and then multiplying by the total number of fuel pin segments in the core (127776 = 31944 fuel pins * 4 axial fuel core layers). The normalization is given by equation 3 where $f_{k,i}$ is the fission density of a pin in node i.

$$F_{k,i} = \frac{f_{k,i} * 127{,}776}{8 * \sum_i \sum_k f_{k,i}} \quad (3)$$

Figures 9-12 show the selected pin fission densities. The bold values represent the normalized fission densities and the values shaded in gray represent the percent uncertainty associated with the normalized fission densities.

2.36	**2.35**	**2.34**	**2.34**	**2.31**	**2.26**	**2.21**	**2.15**	**2.06**
0.16	0.12	0.11	0.11	0.11	0.11	0.12	0.12	0.16
2.77	**2.70**	**2.70**	**2.76**	**2.66**	**2.57**	**2.47**	**2.34**	
0.15	0.11	0.11	0.11	0.11	0.11	0.12	0.16	
	3.00	**3.00**		**2.99**	**2.89**	**2.68**		
	0.11	0.11		0.11	0.11	0.15		
3.13	**3.04**	**3.04**	**3.15**	**3.13**				
0.15	0.11	0.11	0.11	0.11				
3.20	**3.10**	**3.10**	**3.20**	**3.12**				
0.15	0.11	0.11	0.11	0.15				
	3.23	**3.24**						
	0.11	0.11						
3.26	**3.15**	**3.15**						
0.15	0.12	0.15						
3.27	**3.16**							
0.17	0.16							

Figure 9. Normalized pin fission densities and associated percent relative uncertainties; configuration: ARO, assembly: 1, core level: C3

4.70	**4.46**	**4.42**	**4.47**	**4.53**	**4.58**	**4.56**	**4.55**	**4.57**	**4.52**	**4.50**	**4.48**	**4.40**	**4.31**	**4.24**	**4.25**	**4.43**
0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
4.50	**5.28**	**5.05**	**5.09**	**5.24**	**5.50**	**5.22**	**5.21**	**5.44**	**5.17**	**5.16**	**5.41**	**5.10**	**4.93**	**4.86**	**5.04**	**4.25**
0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.11
4.47	**5.07**	**4.89**	**5.17**	**5.28**		**5.06**	**5.01**		**4.99**	**4.99**		**5.18**	**5.03**	**4.74**	**4.87**	**4.27**
0.11	0.11	0.11	0.11	0.11		0.12	0.12		0.12	0.12		0.12	0.12	0.12	0.11	0.11
4.52	**5.12**	**5.17**		**5.15**	**5.61**	**5.16**	**5.11**	**5.39**	**5.09**	**5.13**	**5.54**	**5.06**		**5.03**	**4.95**	**4.34**
0.11	0.11	0.11		0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12		0.12	0.11	0.11
4.57	**5.24**	**5.28**	**5.15**	**5.42**	**5.42**	**4.99**	**4.97**	**5.23**	**4.94**	**4.97**	**5.35**	**5.34**	**5.06**	**5.16**	**5.12**	**4.43**
0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
4.61	**5.50**		**5.59**	**5.40**		**5.23**	**5.19**		**5.18**	**5.19**		**5.33**	**5.53**		**5.39**	**4.50**
0.11	0.11		0.11	0.12		0.12	0.12		0.12	0.12		0.12	0.12		0.11	0.11
4.58	**5.20**	**5.01**	**5.11**	**4.96**	**5.19**	**4.87**	**4.83**	**5.14**	**4.83**	**4.84**	**5.17**	**4.93**	**5.07**	**4.96**	**5.14**	**4.50**
0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
4.54	**5.14**	**4.94**	**5.01**	**4.87**	**5.11**	**4.80**	**4.79**	**5.07**	**4.80**	**4.79**	**5.09**	**4.85**	**4.99**	**4.92**	**5.12**	**4.50**
0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
4.51	**5.34**		**5.25**	**5.10**		**5.03**	**5.03**		**5.03**	**5.04**		**5.10**	**5.25**		**5.33**	**4.52**
0.11	0.11		0.12	0.12		0.12	0.12		0.12	0.12		0.12	0.12		0.11	0.11
4.43	**5.03**	**4.82**	**4.89**	**4.75**	**4.99**	**4.68**	**4.69**	**4.97**	**4.68**	**4.68**	**5.02**	**4.77**	**4.92**	**4.85**	**5.06**	**4.47**
0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
4.36	**4.95**	**4.75**	**4.85**	**4.70**	**4.91**	**4.61**	**4.60**	**4.87**	**4.60**	**4.64**	**4.95**	**4.74**	**4.90**	**4.81**	**5.02**	**4.44**
0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
4.29	**5.10**		**5.16**	**4.97**		**4.82**	**4.79**		**4.81**	**4.84**		**5.03**	**5.25**		**5.23**	**4.41**
0.11	0.12		0.12	0.12		0.12	0.12		0.12	0.12		0.12	0.12		0.11	0.11
4.16	**4.75**	**4.77**	**4.60**	**4.83**	**4.85**	**4.48**	**4.45**	**4.72**	**4.46**	**4.52**	**4.91**	**4.94**	**4.71**	**4.88**	**4.91**	**4.31**
0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11
3.99	**4.48**	**4.52**		**4.45**	**4.82**	**4.45**	**4.39**	**4.67**	**4.43**	**4.49**	**4.91**	**4.56**		**4.67**	**4.66**	**4.18**
0.11	0.12	0.12		0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12		0.12	0.12	0.11
3.84	**4.29**	**4.11**	**4.33**	**4.37**		**4.16**	**4.13**		**4.16**	**4.23**		**4.51**	**4.48**	**4.30**	**4.51**	**4.06**
0.12	0.12	0.12	0.12	0.12		0.13	0.13		0.13	0.13		0.12	0.12	0.12	0.12	0.11
3.71	**4.27**	**4.02**	**3.99**	**4.05**	**4.24**	**3.99**	**3.98**	**4.20**	**4.02**	**4.07**	**4.35**	**4.19**	**4.14**	**4.23**	**4.53**	**3.97**
0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12
3.71	**3.39**	**3.25**	**3.18**	**3.15**	**3.13**	**3.10**	**3.09**	**3.11**	**3.12**	**3.16**	**3.22**	**3.28**	**3.35**	**3.46**	**3.64**	**4.00**
0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12

Figure 10. Normalized pin fission densities and associated percent relative uncertainties; configuration: ARI, assembly: 5, core level: C4

0.46	**0.45**	**0.43**	**0.42**	**0.41**	**0.40**	**0.38**	**0.36**	**0.34**	**0.32**	**0.30**	**0.28**	**0.26**	**0.24**	**0.23**	**0.22**	**0.23**
0.29	0.30	0.30	0.31	0.31	0.32	0.33	0.33	0.34	0.35	0.36	0.38	0.39	0.41	0.42	0.43	0.44
0.42	**0.40**	**0.40**	**0.39**	**0.38**	**0.38**	**0.35**	**0.33**	**0.32**	**0.30**	**0.28**	**0.27**	**0.25**	**0.23**	**0.21**	**0.21**	**0.23**
0.29	0.30	0.30	0.30	0.31	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.40	0.42	0.42	0.42
0.42	**0.41**	**0.41**	**0.42**	**0.41**		**0.37**	**0.35**		**0.32**	**0.30**		**0.27**	**0.25**	**0.23**	**0.22**	**0.24**
0.28	0.29	0.29	0.29	0.30		0.31	0.32		0.34	0.35		0.37	0.38	0.40	0.41	0.41
0.45	**0.44**	**0.45**		**0.44**	**0.41**	**0.38**	**0.36**	**0.36**	**0.33**	**0.31**	**0.30**	**0.29**		**0.26**	**0.24**	**0.27**
0.27	0.28	0.28		0.29	0.29	0.30	0.31	0.31	0.32	0.33	0.34	0.35		0.38	0.39	0.39
0.48	**0.48**	**0.50**	**0.49**	**0.46**	**0.45**	**0.42**	**0.40**	**0.39**	**0.36**	**0.34**	**0.33**	**0.31**	**0.30**	**0.28**	**0.27**	**0.29**
0.26	0.26	0.27	0.27	0.27	0.28	0.29	0.29	0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.37
0.53	**0.54**		**0.52**	**0.51**		**0.46**	**0.44**		**0.40**	**0.38**		**0.34**	**0.32**		**0.31**	**0.33**
0.25	0.25		0.26	0.26		0.27	0.28		0.29	0.30		0.32	0.33		0.35	0.35
0.57	**0.56**	**0.57**	**0.54**	**0.53**	**0.52**	**0.49**	**0.47**	**0.46**	**0.42**	**0.40**	**0.39**	**0.36**	**0.34**	**0.33**	**0.33**	**0.36**
0.24	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.28	0.28	0.29	0.30	0.31	0.32	0.33	0.33	0.33
0.61	**0.61**	**0.62**	**0.59**	**0.57**	**0.57**	**0.53**	**0.50**	**0.50**	**0.46**	**0.44**	**0.42**	**0.39**	**0.37**	**0.37**	**0.36**	**0.40**
0.23	0.23	0.24	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.28	0.29	0.30	0.31	0.31	0.32	0.32
0.66	**0.67**		**0.65**	**0.63**		**0.58**	**0.56**		**0.51**	**0.48**		**0.43**	**0.41**		**0.40**	**0.44**
0.22	0.23		0.23	0.23		0.24	0.25		0.26	0.27		0.28	0.29		0.30	0.30
0.69	**0.69**	**0.70**	**0.67**	**0.65**	**0.65**	**0.60**	**0.58**	**0.57**	**0.53**	**0.50**	**0.49**	**0.45**	**0.43**	**0.43**	**0.43**	**0.48**
0.22	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.27	0.27	0.28	0.29	0.29	0.29
0.74	**0.73**	**0.75**	**0.71**	**0.69**	**0.69**	**0.64**	**0.62**	**0.61**	**0.56**	**0.54**	**0.53**	**0.49**	**0.47**	**0.47**	**0.47**	**0.53**
0.21	0.21	0.21	0.22	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.26	0.26	0.27	0.28	0.28	0.28
0.77	**0.79**		**0.78**	**0.76**		**0.70**	**0.67**		**0.62**	**0.59**		**0.54**	**0.52**		**0.51**	**0.57**
0.20	0.21		0.21	0.21		0.22	0.23		0.24	0.24		0.26	0.26		0.27	0.27
0.80	**0.80**	**0.83**	**0.82**	**0.78**	**0.76**	**0.71**	**0.68**	**0.67**	**0.62**	**0.60**	**0.59**	**0.56**	**0.55**	**0.54**	**0.53**	**0.61**
0.20	0.20	0.20	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.26
0.82	**0.81**	**0.84**		**0.82**	**0.79**	**0.73**	**0.70**	**0.70**	**0.65**	**0.62**	**0.62**	**0.59**		**0.55**	**0.55**	**0.64**
0.20	0.20	0.20		0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24		0.25	0.26	0.25
0.83	**0.81**	**0.81**	**0.83**	**0.81**		**0.76**	**0.73**		**0.67**	**0.65**		**0.60**	**0.57**	**0.54**	**0.56**	**0.65**
0.19	0.20	0.20	0.20	0.20		0.21	0.21		0.22	0.23		0.24	0.24	0.25	0.25	0.25
0.83	**0.80**	**0.78**	**0.77**	**0.76**	**0.76**	**0.71**	**0.69**	**0.68**	**0.64**	**0.61**	**0.60**	**0.56**	**0.54**	**0.52**	**0.54**	**0.64**
0.19	0.20	0.20	0.20	0.20	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.25	0.25	0.25	0.24
0.80	**0.75**	**0.72**	**0.70**	**0.69**	**0.67**	**0.65**	**0.63**	**0.61**	**0.58**	**0.56**	**0.54**	**0.51**	**0.49**	**0.48**	**0.50**	**0.58**
0.19	0.20	0.20	0.20	0.21	0.21	0.21	0.22	0.22	0.23	0.23	0.23	0.24	0.25	0.25	0.25	0.25

Figure 11. Normalized pin fission densities and associated percent relative uncertainties; configuration: SRI, assembly: 19, core level: C2

1.88	**1.87**	**1.86**	**1.87**	**1.83**	**1.79**	**1.75**	**1.70**	**1.62**
0.18	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.19
2.22	**2.15**	**2.15**	**2.20**	**2.12**	**2.05**	**1.97**	**1.86**	
0.17	0.13	0.12	0.12	0.12	0.13	0.13	0.18	
	2.39	**2.40**		**2.38**	**2.30**	**2.13**		
	0.12	0.12		0.12	0.13	0.17		
2.50	**2.43**	**2.43**	**2.52**	**2.50**				
0.17	0.12	0.12	0.12	0.13				
2.56	**2.47**	**2.48**	**2.56**	**2.49**				
0.17	0.12	0.12	0.12	0.16				
	2.59	**2.59**						
	0.12	0.13						
2.61	**2.53**	**2.53**						
0.17	0.13	0.17						
2.62	**2.53**							
0.19	0.18							

Figure 12. Normalized pin fission densities and associated percent relative uncertainties; configuration: SRI, assembly: 1, core Level: C3

CHAPTER 8

CONCLUSION

In this paper, we have developed three configurations of a stylized 3-dimensional pressurized water reactor benchmark problem with UO_2 and MOX fuel. Although stylized, its geometric configuration is representative of a small PWR core based on a Westinghouse 2-loop reactor design. The material distribution in the design has been modified to include MOX assemblies and the specific assembly configurations were based on the C5G7 benchmark problem found in literature. The simplifications, including a Cartesian boundary and control rod homogenization, were carefully chosen to retain the important physics of the problem. The specification is both complex enough to test new and existing codes and simple enough to remain tractable for methods development. The Monte Carlo benchmark results presented are intended to serve as a tool for validating codes and methods for whole core calculations using the 2, 4, and 8 group cross-sections presented in this paper. It is important to have a set of common cross sections for verification and evaluation of the accuracy of methods. These cross sections have been developed using the lattice depletion transport code HELIOS. In addition to these cross sections, the material compositions have been provided, allowing for both independent cross section generation and continuous energy computations.

APPENDIX A
MATERIAL SPECIFICATIONS

Material Number Densities (10^{24} atoms/cm^3)								
	MOX 4.3%	MOX 7.0%	MOX 8.7%	UO2	Moderator	Center Tube	Control	Zr clad
U-235	5.00E-05	5.00E-05	5.00E-05	8.65E-04		1.0000E-08		
U-238	2.21E-02	2.21E-02	2.21E-02	2.23E-02				
Pu-238	1.50E-05	2.40E-02	3.00E-05					
Pu-239	5.80E-04	9.30E-04	1.16E-03					
Pu-240	2.40E-04	3.90E-04	4.90E-04					
Pu-241	9.80E-05	1.52E-04	1.90E-04					
Pu-242	5.40E-05	8.40E-05	1.05E-04					
Am-241	1.30E-05	2.00E-05	2.50E-05					
O	4.63E-02	4.63E-02	4.63E-02	4.62E-02	2.4439E-02	2.4439E-02		
H					4.8879E-02	4.8879E-02		
B-10					2.3199E-05	2.3199E-05		
B-11					9.3377E-05	9.3377E-05		
Nat B							8.0214E-02	
Nat C							2.0053E-02	
Nat Zr								4.30E-02

APPENDIX B

2-GROUP CROSS SECTION LIBRARY

Each unique assembly type is given its own section, and for each material in that assembly, the cross sections are presented in the following order:

$$\{\sigma_{cg}\}_{g=1}^{G}, \{\sigma_{fg}\}_{g=1}^{G}, \{\nu_g\}_{g=1}^{G}, \{\chi_g\}_{g=1}^{G}, \left\{\left\{\{\sigma_{sn}^{g'\to g}\}_{g'=1}^{G}\right\}_{g=1}^{G}\right\}_{n=0}^{N}$$

where, for G energy groups σ_{cg} is the group g capture cross section, σ_{fg} is the group g fission cross section, ν_g is the group g fission yield (i.e. $\nu\sigma_{fg} = \nu_g\sigma_{fg}$), χ_g is the fission spectrum corresponding to group g, and $\sigma_{sn}^{g'\to g}$ is the n^{th} (of N) Legendre moment of the scattering cross section from group g' to group g.

Controlled UO_2 Assembly

```
 Moderator
  1.0682E-03  5.0399E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
  0.0000E+00  0.0000E+00  6.2977E-01  3.5293E-03  1.9155E-02  1.7538E+00
  3.7280E-01  2.2440E-03  5.5129E-03  5.4648E-01

 Zirconium Cladding
  1.7926E-03  3.7730E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
  0.0000E+00  0.0000E+00  3.2117E-01  1.3275E-03  1.8015E-04  2.7379E-01
  3.9607E-02 -1.6358E-04 -4.2319E-05  2.6201E-03

 UO2 Fuel
  2.7096E-02  2.8914E-01  8.4457E-03  2.1016E-01  2.5393E+00  2.4338E+00
  1.0000E+00  0.0000E+00  3.9732E-01  3.0351E-03  5.1229E-04  4.0247E-01
  4.4845E-02 -2.7387E-04 -1.1945E-04  8.9788E-03

 Central Guide Tube
  1.2301E-03  5.3287E-02  8.6554E-08  2.7308E-06  2.4447E+00  2.4338E+00
  1.0000E+00  0.0000E+00  6.4738E-01  2.9788E-03  2.2851E-02  1.8113E+00
  3.8493E-01  1.8923E-03  6.5943E-03  5.4376E-01

 Control Material
  2.0865E-01  2.3065E+01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
  0.0000E+00  0.0000E+00  3.4200E-01  4.4436E-03  1.5946E-04  4.4296E-01
  2.9692E-02  3.0908E-05 -8.4349E-06  2.7596E-02

Homogenized Tube Region
  1.3336E-03  2.6987E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
  0.0000E+00  0.0000E+00  4.7204E-01  2.5658E-03  7.2333E-03  1.0168E+00
  2.0331E-01  1.1394E-03  2.0161E-03  2.7974E-01
```

Uncontrolled UO_2 Assembly

Moderator
1.3528E-03 5.2692E-02 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 6.4006E-01 2.8266E-03 2.6664E-02 1.7995E+00
3.8083E-01 1.7942E-03 7.8354E-03 5.4470E-01

Zirconium Cladding
1.7977E-03 3.9238E-03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 3.1821E-01 1.0760E-03 2.6698E-04 2.7411E-01
3.8207E-02 -1.3268E-04 -6.2719E-05 2.5835E-03

UO_2 Fuel
2.9958E-02 2.9977E-01 9.3033E-03 2.1920E-01 2.5288E+00 2.4338E+00
1.0000E+00 0.0000E+00 3.9751E-01 2.4896E-03 7.5954E-04 4.0344E-01
4.3746E-02 -2.2744E-04 -1.7636E-04 8.9230E-03

Central Guide Tube
1.4258E-03 5.4535E-02 9.3517E-08 2.8011E-06 2.4439E+00 2.4338E+00
1.0000E+00 0.0000E+00 6.4911E-01 2.5299E-03 2.8299E-02 1.8362E+00
3.8701E-01 1.6049E-03 8.3114E-03 5.4288E-01

Uncontrolled MOX Assembly

Moderator
1.1422E-03 4.8902E-02 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 6.3295E-01 5.1239E-03 1.9781E-02 1.7229E+00
3.7557E-01 3.2741E-03 5.5520E-03 5.4629E-01

Zirconium Cladding
1.7994E-03 3.6613E-03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 3.1819E-01 2.1361E-03 1.6459E-04 2.7295E-01
3.9136E-02 -2.6155E-04 -3.8617E-05 2.7256E-03

Mox 4.3% TRU Fuel
3.6351E-02 8.0558E-01 8.7019E-03 4.5821E-01 2.8631E+00 2.8656E+00
1.0000E+00 0.0000E+00 3.9852E-01 5.3526E-03 4.4357E-04 3.9425E-01
4.4643E-02 -4.3981E-04 -9.6601E-05 9.1460E-03

MOX 7.0% TRU Fuel
4.4000E-02 1.2155E+00 1.1940E-02 6.9804E-01 2.8799E+00 2.8698E+00
1.0000E+00 0.0000E+00 4.0355E-01 5.6992E-03 4.2196E-04 3.9830E-01
4.5950E-02 -4.6591E-04 -9.1072E-05 9.1961E-03

MOX 8.7% TRU Fuel
4.7280E-02 1.4691E+00 1.3798E-02 8.4589E-01 2.8875E+00 2.8712E+00
1.0000E+00 0.0000E+00 4.0609E-01 6.2538E-03 3.8550E-04 4.0062E-01
4.7059E-02 -5.0798E-04 -8.2689E-05 9.2584E-03

Central Guide Tube
1.2034E-03 5.0565E-02 8.4610E-08 2.5716E-06 2.4458E+00 2.4338E+00
1.0000E+00 0.0000E+00 6.3897E-01 4.3755E-03 2.1309E-02 1.7568E+00
3.7975E-01 2.7912E-03 6.0208E-03 5.4525E-01

APPENDIX C

4-GROUP CROSS SECTION LIBRARY

Controlled UO_2 Assembly

Moderator

1.5746E-04	1.6319E-03	1.3758E-02	5.0399E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.8428E-01	0.0000E+00
0.0000E+00	0.0000E+00	6.7765E-02	9.9848E-01	0.0000E+00	0.0000E+00
2.1991E-05	7.3603E-02	7.2445E-01	3.5293E-03	1.6988E-06	1.3754E-02
4.0971E-01	1.7538E+00	2.2428E-01	0.0000E+00	0.0000E+00	0.0000E+00
2.9613E-02	6.2875E-01	0.0000E+00	0.0000E+00	0.0000E+00	3.3709E-02
4.8131E-01	2.2440E-03	0.0000E+00	2.3189E-03	1.2968E-01	5.4648E-01

Zirconium Cladding

5.9772E-04	5.0604E-03	1.0360E-03	3.7730E-03	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.1660E-01	0.0000E+00
0.0000E+00	0.0000E+00	5.7146E-04	3.3857E-01	0.0000E+00	0.0000E+00
0.0000E+00	4.8016E-04	2.6926E-01	1.3275E-03	0.0000E+00	0.0000E+00
4.8446E-03	2.7379E-01	5.5698E-02	0.0000E+00	0.0000E+00	0.0000E+00
-1.4565E-04	2.6575E-03	0.0000E+00	0.0000E+00	0.0000E+00	-1.5768E-04
3.5212E-03	-1.6358E-04	0.0000E+00	0.0000E+00	-1.1381E-03	2.6201E-03

UO_2 Fuel

8.2399E-03	7.5888E-02	5.1233E-02	2.8914E-01	4.5117E-03	1.6178E-02
3.0788E-02	2.1016E-01	2.7127E+00	2.4338E+00	2.4338E+00	2.4338E+00
9.9967E-01	3.3212E-04	0.0000E+00	0.0000E+00	3.6068E-01	0.0000E+00
0.0000E+00	0.0000E+00	1.6949E-03	4.9486E-01	0.0000E+00	0.0000E+00
0.0000E+00	1.8445E-03	3.7854E-01	3.0351E-03	0.0000E+00	0.0000E+00
1.4169E-02	4.0247E-01	6.0221E-02	0.0000E+00	0.0000E+00	0.0000E+00
-5.1974E-04	8.9248E-03	0.0000E+00	0.0000E+00	0.0000E+00	-5.5963E-04
1.1951E-02	-2.7387E-04	0.0000E+00	0.0000E+00	-3.3037E-03	8.9788E-03

Central Guide Tube

1.5956E-04	1.7350E-03	1.3781E-02	5.3287E-02	1.4104E-08	2.0898E-07
3.6123E-07	2.7308E-06	2.5346E+00	2.4338E+00	2.4338E+00	2.4338E+00
9.9967E-01	3.2919E-04	0.0000E+00	0.0000E+00	3.8573E-01	0.0000E+00
0.0000E+00	0.0000E+00	6.9899E-02	9.9028E-01	0.0000E+00	0.0000E+00
2.2755E-05	8.1028E-02	7.2323E-01	2.9788E-03	1.7597E-06	1.5142E-02
4.1109E-01	1.8113E+00	2.2561E-01	0.0000E+00	0.0000E+00	0.0000E+00
3.0628E-02	6.2505E-01	0.0000E+00	0.0000E+00	0.0000E+00	3.7554E-02
4.8059E-01	1.8923E-03	0.0000E+00	2.5847E-03	1.3027E-01	5.4376E-01

Control Material

1.9710E-02	6.5912E-01	7.4552E+00	2.3065E+01	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.0771E-01	0.0000E+00
0.0000E+00	0.0000E+00	5.4619E-03	4.3808E-01	0.0000E+00	0.0000E+00
0.0000E+00	1.8917E-03	4.1572E-01	4.4436E-03	0.0000E+00	0.0000E+00
2.5323E-02	4.4296E-01	3.0935E-02	0.0000E+00	0.0000E+00	0.0000E+00
-3.4632E-04	2.6732E-02	0.0000E+00	0.0000E+00	0.0000E+00	-1.1379E-04
2.8418E-02	3.0908E-05	0.0000E+00	0.0000E+00	-1.3396E-03	2.7596E-02

Homogenized Tube Region

3.7898E-04	3.3702E-03	7.4622E-03	2.6987E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.5173E-01	0.0000E+00
0.0000E+00	0.0000E+00	3.4501E-02	6.7874E-01	0.0000E+00	0.0000E+00
1.1105E-05	3.2366E-02	5.0270E-01	2.5658E-03	8.5778E-07	6.0168E-03
2.0828E-01	1.0168E+00	1.4025E-01	0.0000E+00	0.0000E+00	0.0000E+00
1.4878E-02	3.2031E-01	0.0000E+00	0.0000E+00	0.0000E+00	1.4358E-02
2.4751E-01	1.1394E-03	0.0000E+00	9.9047E-04	6.4436E-02	2.7974E-01

Uncontrolled UO_2 Assembly

Moderator

1.6257E-04	1.7881E-03	1.3903E-02	5.2692E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.8131E-01	0.0000E+00
0.0000E+00	0.0000E+00	6.6979E-02	9.8575E-01	0.0000E+00	0.0000E+00
2.1744E-05	8.5106E-02	7.1667E-01	2.8266E-03	1.6802E-06	1.5892E-02
4.1849E-01	1.7995E+00	2.2245E-01	0.0000E+00	0.0000E+00	0.0000E+00
2.9280E-02	6.2277E-01	0.0000E+00	0.0000E+00	0.0000E+00	3.9868E-02
4.7674E-01	1.7942E-03	0.0000E+00	2.7458E-03	1.3336E-01	5.4470E-01

Zirconium Cladding

5.9280E-04	4.8443E-03	1.0468E-03	3.9238E-03	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.1493E-01	0.0000E+00
0.0000E+00	0.0000E+00	5.6383E-04	3.3334E-01	0.0000E+00	0.0000E+00
0.0000E+00	5.8944E-04	2.6895E-01	1.0760E-03	0.0000E+00	0.0000E+00
5.1599E-03	2.7411E-01	5.5838E-02	0.0000E+00	0.0000E+00	0.0000E+00
-1.4370E-04	2.6556E-03	0.0000E+00	0.0000E+00	0.0000E+00	-1.9357E-04
3.6033E-03	-1.3268E-04	0.0000E+00	0.0000E+00	-1.2121E-03	2.5835E-03

UO_2 Fuel

8.2920E-03	8.0691E-02	5.1813E-02	2.9977E-01	4.5995E-03	1.7064E-02
3.1378E-02	2.1920E-01	2.7161E+00	2.4338E+00	2.4338E+00	2.4338E+00
9.9967E-01	3.3212E-04	0.0000E+00	0.0000E+00	3.5906E-01	0.0000E+00
0.0000E+00	0.0000E+00	1.6695E-03	4.9203E-01	0.0000E+00	0.0000E+00
0.0000E+00	2.2706E-03	3.7785E-01	2.4896E-03	0.0000E+00	0.0000E+00
1.5046E-02	4.0344E-01	6.0581E-02	0.0000E+00	0.0000E+00	0.0000E+00
-5.1189E-04	9.0519E-03	0.0000E+00	0.0000E+00	0.0000E+00	-6.8742E-04
1.2151E-02	-2.2744E-04	0.0000E+00	0.0000E+00	-3.4936E-03	8.9230E-03

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1.6388E-04	1.8312E-03	1.3911E-02	5.4535E-02	1.4058E-08	2.1576E-07
3.6725E-07	2.8011E-06	2.5374E+00	2.4338E+00	2.4338E+00	2.4338E+00
9.9967E-01	3.2919E-04	0.0000E+00	0.0000E+00	3.8240E-01	0.0000E+00
0.0000E+00	0.0000E+00	6.8378E-02	9.8217E-01	0.0000E+00	0.0000E+00
2.2242E-05	8.8313E-02	7.1624E-01	2.5299E-03	1.7199E-06	1.6494E-02
4.1898E-01	1.8362E+00	2.2340E-01	0.0000E+00	0.0000E+00	0.0000E+00
2.9942E-02	6.2116E-01	0.0000E+00	0.0000E+00	0.0000E+00	4.1517E-02
4.7648E-01	1.6049E-03	0.0000E+00	2.8596E-03	1.3357E-01	5.4288E-01

Uncontrolled MOX Assembly

Moderator

1.7506E-04	1.7244E-03	1.3362E-02	4.8902E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.7832E-01	0.0000E+00
0.0000E+00	0.0000E+00	6.6219E-02	9.9102E-01	0.0000E+00	0.0000E+00
2.1498E-05	8.0233E-02	7.4494E-01	5.1239E-03	1.6613E-06	1.4988E-02
3.8630E-01	1.7229E+00	2.2065E-01	0.0000E+00	0.0000E+00	0.0000E+00
2.8948E-02	6.2523E-01	0.0000E+00	0.0000E+00	0.0000E+00	3.7260E-02
4.9341E-01	3.2741E-03	0.0000E+00	2.5651E-03	1.1989E-01	5.4629E-01

Zirconium Cladding

5.8544E-04	4.9601E-03	9.9650E-04	3.6613E-03	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.1330E-01	0.0000E+00
0.0000E+00	0.0000E+00	5.5806E-04	3.3524E-01	0.0000E+00	0.0000E+00
0.0000E+00	5.2475E-04	2.6973E-01	2.1361E-03	0.0000E+00	0.0000E+00
4.3632E-03	2.7295E-01	5.5829E-02	0.0000E+00	0.0000E+00	0.0000E+00
-1.4223E-04	2.6479E-03	0.0000E+00	0.0000E+00	0.0000E+00	-1.7233E-04
3.3859E-03	-2.6155E-04	0.0000E+00	0.0000E+00	-1.0237E-03	2.7256E-03

MOX 4.3% TRU Fuel

8.5766E-03	8.2578E-02	2.3265E-01	8.0558E-01	4.9097E-03	1.7173E-02
1.9017E-02	4.5821E-01	2.8672E+00	2.8612E+00	2.8549E+00	2.8656E+00
9.9967E-01	3.3046E-04	0.0000E+00	0.0000E+00	3.5900E-01	0.0000E+00
0.0000E+00	0.0000E+00	1.6921E-03	4.9508E-01	0.0000E+00	0.0000E+00
0.0000E+00	2.0217E-03	3.9395E-01	5.3526E-03	0.0000E+00	0.0000E+00
1.2602E-02	3.9425E-01	6.0838E-02	0.0000E+00	0.0000E+00	0.0000E+00
-5.1672E-04	9.0099E-03	0.0000E+00	0.0000E+00	0.0000E+00	-6.2445E-04
1.1422E-02	-4.3981E-04	0.0000E+00	0.0000E+00	-2.7444E-03	9.1460E-03

MOX 7.0% TRU Fuel

9.5914E-03	1.0002E-01	3.1355E-01	1.2155E+00	5.8423E-03	2.5796E-02
2.9041E-02	6.9804E-01	2.8985E+00	2.8706E+00	2.8671E+00	2.8698E+00
9.9967E-01	3.2969E-04	0.0000E+00	0.0000E+00	3.6236E-01	0.0000E+00
0.0000E+00	0.0000E+00	1.6761E-03	5.0518E-01	0.0000E+00	0.0000E+00
0.0000E+00	2.0218E-03	4.0598E-01	5.6992E-03	0.0000E+00	0.0000E+00
1.2386E-02	3.9830E-01	6.2401E-02	0.0000E+00	0.0000E+00	0.0000E+00
-5.1018E-04	9.0516E-03	0.0000E+00	0.0000E+00	0.0000E+00	-6.2672E-04
1.1391E-02	-4.6591E-04	0.0000E+00	0.0000E+00	-2.6733E-03	9.1961E-03

MOX 8.7% TRU Fuel

1.0267E-02	1.0938E-01	3.5416E-01	1.4691E+00	6.4706E-03	3.0941E-02
3.5277E-02	8.4589E-01	2.9148E+00	2.8742E+00	2.8717E+00	2.8712E+00
9.9967E-01	3.2954E-04	0.0000E+00	0.0000E+00	3.6445E-01	0.0000E+00
0.0000E+00	0.0000E+00	1.6585E-03	5.1120E-01	0.0000E+00	0.0000E+00
0.0000E+00	1.9879E-03	4.1333E-01	6.2538E-03	0.0000E+00	0.0000E+00
1.1945E-02	4.0062E-01	6.3491E-02	0.0000E+00	0.0000E+00	0.0000E+00
-5.0374E-04	9.0669E-03	0.0000E+00	0.0000E+00	0.0000E+00	-6.1833E-04
1.1300E-02	-5.0798E-04	0.0000E+00	0.0000E+00	-2.5622E-03	9.2584E-03

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1.7701E-04	1.7567E-03	1.3472E-02	5.0565E-02	1.4025E-08	2.1067E-07
3.3658E-07	2.5716E-06	2.5421E+00	2.4338E+00	2.4338E+00	2.4338E+00
9.9967E-01	3.2919E-04	0.0000E+00	0.0000E+00	3.7876E-01	0.0000E+00
0.0000E+00	0.0000E+00	6.7185E-02	9.8846E-01	0.0000E+00	0.0000E+00
2.1847E-05	8.2702E-02	7.3959E-01	4.3755E-03	1.6891E-06	1.5452E-02
3.9259E-01	1.7568E+00	2.2114E-01	0.0000E+00	0.0000E+00	0.0000E+00
2.9411E-02	6.2416E-01	0.0000E+00	0.0000E+00	0.0000E+00	3.8493E-02
4.9029E-01	2.7912E-03	0.0000E+00	2.6498E-03	1.2247E-01	5.4525E-01

APPENDIX D

8-GROUP CROSS SECTION LIBRARY

Controlled UO_2 Assembly

Moderator

7.8889E-04	9.5362E-06	4.8592E-05	5.6436E-04	3.6563E-03	1.3758E-02
3.1774E-02	7.0195E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	6.1505E-02	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.1062E-02	1.2238E-01
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2.7836E-02	1.3000E-01	5.0564E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	3.0888E-04	1.2996E-03	1.1235E-01	8.6695E-01
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.2306E-05
1.5550E-03	2.0645E-01	8.5639E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	3.7171E-05	5.3431E-03	2.0306E-01	7.2445E-01
6.8501E-03	0.0000E+00	0.0000E+00	0.0000E+00	2.8714E-06	7.7545E-04
2.9091E-02	3.4005E-01	9.4809E-01	1.8764E-01	0.0000E+00	0.0000E+00
0.0000E+00	2.2782E-04	8.8435E-03	6.9660E-02	4.3724E-01	1.9578E+00
3.5000E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	3.3201E-02	6.6596E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	9.9111E-03	5.9893E-02
3.0487E-01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1.2734E-05	8.4546E-05	4.9926E-02	5.6785E-01	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	8.8150E-05	9.2386E-02
5.6905E-01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	4.7859E-04	9.6731E-02	4.8131E-01	4.3554E-03	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	1.0373E-05	5.9273E-03	1.2437E-01
5.0428E-01	3.5569E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
7.6957E-04	5.3076E-03	5.9178E-02	4.9286E-01		

Zirconium Cladding

8.6984E-05	4.9489E-04	7.7966E-04	7.5477E-03	2.5829E-04	1.0360E-03
2.4042E-03	5.2846E-03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	1.1824E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	3.4629E-02	2.2885E-01
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2.0630E-02	1.5861E-02	3.8584E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	9.6850E-04	3.7311E-01
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	1.1605E-03	2.6964E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.4072E-03	2.6926E-01
2.5295E-03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	4.8446E-03	2.6072E-01	1.0169E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.1222E-02	2.6567E-01
5.3354E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	-4.6229E-04	7.9998E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-1.6602E-05	-7.4308E-04
4.6478E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	-2.4684E-04	3.1421E-03	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-3.8248E-04

2.4602E-03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 -4.6211E-04 3.5212E-03 -3.1170E-04 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 -1.1381E-03
4.9847E-03 -1.8243E-03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 -2.1580E-03 4.2163E-03

UO_2 Fuel
1.4525E-02 8.1069E-03 6.5642E-03 3.9684E-02 1.4817E-01 5.1233E-02
1.7715E-01 4.2208E-01 1.3520E-02 6.1306E-03 1.3335E-03 8.3703E-03
3.1767E-02 3.0788E-02 1.3113E-01 3.0398E-01 2.8781E+00 2.6114E+00
2.4506E+00 2.4338E+00 2.4338E+00 2.4338E+00 2.4338E+00 2.4338E+00
3.5048E-01 4.1069E-01 2.3851E-01 3.3212E-04 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 1.7434E-01 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 3.6161E-02 2.3770E-01
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
2.2561E-02 5.9173E-02 4.2325E-01 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 8.1966E-06 1.5434E-05 2.8807E-03 5.0566E-01
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 4.8519E-03 4.6362E-01 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 5.5272E-03 3.7854E-01
5.5918E-03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 1.4169E-02 3.6996E-01 2.9871E-02 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 2.5971E-02 3.8036E-01
9.7135E-02 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 -3.9539E-04 7.3243E-02 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 2.9219E-04 -1.0849E-02
4.9140E-02 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
4.7763E-07 0.0000E+00 -8.8623E-04 9.8568E-03 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 -1.4942E-03
1.0047E-02 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 -1.6770E-03 1.1951E-02 -5.0458E-04 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 -3.3035E-03
1.3654E-02 -4.9274E-03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 -2.6416E-07 -4.3564E-03 1.3528E-02

Central Guide Tube
7.9230E-04 9.5600E-06 4.9370E-05 5.6929E-04 3.7197E-03 1.3781E-02
3.2114E-02 7.1870E-02 1.2046E-08 1.2156E-08 1.5465E-08 9.9045E-08
3.9615E-07 3.6123E-07 1.5463E-06 3.7705E-06 2.8702E+00 2.5799E+00
2.4489E+00 2.4338E+00 2.4338E+00 2.4338E+00 2.4338E+00 2.4338E+00
3.5044E-01 4.1109E-01 2.3814E-01 3.2919E-04 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 6.1508E-02 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 5.1020E-02 1.2240E-01
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
2.7814E-02 1.2975E-01 5.0740E-01 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 3.0862E-04 1.2975E-03 1.1544E-01 8.6011E-01
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 1.2272E-05
1.5978E-03 2.1334E-01 8.4868E-01 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 3.8304E-05 5.5211E-03 2.0959E-01 7.2323E-01
6.3729E-03 0.0000E+00 0.0000E+00 0.0000E+00 2.9622E-06 8.0128E-04
3.0030E-02 3.4121E-01 9.4327E-01 1.8248E-01 0.0000E+00 0.0000E+00
0.0000E+00 2.3583E-04 9.1289E-03 6.9879E-02 4.4904E-01 1.9966E+00
3.5004E-02 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 3.3170E-02 6.6630E-02 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 9.9017E-03 5.9782E-02
3.0653E-01 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
1.2720E-05 8.4354E-05 5.1429E-02 5.6470E-01 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 9.0937E-05 9.5683E-02
5.6489E-01 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 4.9615E-04 1.0065E-01 4.8059E-01 4.0484E-03 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 1.0754E-05 6.1658E-03 1.2495E-01
5.0177E-01 3.3213E-02 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
8.0153E-04 5.3228E-03 6.1846E-02 4.9312E-01

Control Material

6.3239E-03	5.3471E-03	2.9205E-02	3.2284E-01	1.8181E+00	7.4552E+00
1.7561E+01	3.6161E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	1.2374E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.0710E-02	1.9994E-01
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1.0254E-03	3.3814E-02	3.7311E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	9.1698E-03	4.2526E-01
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	1.4590E-02	4.3197E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	8.4116E-03	4.1572E-01
6.3109E-03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	2.5322E-02	3.9251E-01	4.9394E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	1.2135E-06	4.5013E-02	4.0649E-01
3.6804E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	-3.9170E-03	2.5757E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-1.9931E-03
3.3425E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	-5.8143E-04	2.7503E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-8.8718E-04
2.7131E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	-5.0594E-04	2.8418E-02	4.3897E-05	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-1.3390E-03
2.9462E-02	-1.0217E-03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	-5.3014E-07	-1.8097E-03	2.8484E-02		

Homogenized Tube Region

4.3710E-04	2.5256E-04	4.1625E-04	4.0185E-03	1.9271E-03	7.4622E-03
1.7266E-02	3.8058E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	8.9880E-02	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.2850E-02	1.7573E-01
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2.4233E-02	7.2952E-02	4.4631E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	1.5442E-04	6.4977E-04	5.6932E-02	6.2361E-01
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	6.1588E-06
7.8117E-04	1.0279E-01	5.7261E-01	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	1.8677E-05	2.6455E-03	9.8534E-02	5.0270E-01
4.8190E-03	0.0000E+00	0.0000E+00	0.0000E+00	1.4427E-06	3.8395E-04
1.4039E-02	1.7322E-01	6.1174E-01	1.0108E-01	0.0000E+00	0.0000E+00
0.0000E+00	1.1261E-04	4.2677E-03	3.5053E-02	2.2508E-01	1.1206E+00
4.4181E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	1.6368E-02	7.3313E-02	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.9469E-03	2.9577E-02
1.7564E-01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6.3668E-06	4.2294E-05	2.4959E-02	2.8732E-01	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.4289E-05	4.5454E-02
2.9256E-01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	2.3622E-04	4.5798E-02	2.4751E-01	2.1399E-03	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	5.1200E-06	2.8189E-03	6.1760E-02
2.5954E-01	1.7593E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3.6534E-04	2.6762E-03	2.8478E-02	2.5272E-01		

Uncontrolled UO_2 Assembly

Moderator

7.9279E-04	9.5593E-06	4.8626E-05	5.7197E-04	3.7685E-03	1.3903E-02
3.2344E-02	7.0585E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

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 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  6.1546E-02  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  5.0994E-02  1.2243E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.7802E-02  1.2946E-01  5.0549E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.0848E-04  1.2951E-03  1.1259E-01  8.6243E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.2233E-05
 1.5583E-03  2.1123E-01  8.4256E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.7268E-05  5.4665E-03  2.1481E-01  7.1667E-01
 6.0409E-03  0.0000E+00  0.0000E+00  0.0000E+00  2.8798E-06  7.9335E-04
 3.0752E-02  3.4745E-01  9.4000E-01  1.8561E-01  0.0000E+00  0.0000E+00
 0.0000E+00  2.3356E-04  9.3484E-03  7.1034E-02  4.5708E-01  1.9677E+00
 3.5028E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.3151E-02  6.6670E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  9.8959E-03  5.9656E-02
 3.0483E-01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 1.2715E-05  8.4136E-05  5.0056E-02  5.6572E-01  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  8.8407E-05  9.4766E-02
 5.6134E-01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  4.9147E-04  1.0399E-01  4.7674E-01  3.8346E-03  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  1.0652E-05  6.3716E-03  1.2797E-01
 5.0006E-01  3.4632E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 8.2874E-04  5.3941E-03  6.3656E-02  4.9335E-01
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Zirconium Cladding

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 8.5867E-05  4.9487E-04  7.7962E-04  7.5918E-03  2.6666E-04  1.0468E-03
 2.4452E-03  5.2997E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  1.1824E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  3.4630E-02  2.2862E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.0616E-02  1.5864E-02  3.8573E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  9.6866E-04  3.7040E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  1.1932E-03  2.6961E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.5715E-03  2.6895E-01
 2.2322E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  5.1599E-03  2.5974E-01  9.9018E-03  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.2506E-02  2.6594E-01
 5.3368E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -4.6173E-04  7.9909E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -1.6576E-05 -7.3678E-04
 4.6570E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -2.4688E-04  3.1331E-03  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -3.9322E-04
 2.5152E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -5.1609E-04  3.6033E-03 -2.7525E-04  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -1.2121E-03
 5.1851E-03 -1.7825E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -2.3948E-03  4.1735E-03
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UO_2 Fuel

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 1.4528E-02  8.1357E-03  6.5577E-03  4.0139E-02  1.5049E-01  5.1813E-02
 1.8079E-01  4.1922E-01  1.3525E-02  6.1639E-03  1.3326E-03  8.4840E-03
 3.1832E-02  3.1378E-02  1.3398E-01  3.0476E-01  2.8789E+00  2.6115E+00
 2.4507E+00  2.4338E+00  2.4338E+00  2.4338E+00  2.4338E+00  2.4338E+00
 3.5048E-01  4.1069E-01  2.3851E-01  3.3212E-04  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  1.7435E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  3.6135E-02  2.3746E-01
```

```
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.2558E-02  5.9008E-02  4.2296E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  8.2579E-06  1.5402E-05  2.8757E-03  5.0561E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  4.9842E-03  4.6006E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  6.1786E-03  3.7785E-01
 4.9694E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  1.5046E-02  3.6814E-01  2.9401E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  2.8524E-02  3.8085E-01
 9.7138E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -3.9323E-04  7.3158E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  2.9199E-04 -1.0764E-02
 4.9247E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 4.8181E-07  0.0000E+00 -8.8469E-04  9.9007E-03  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -1.5350E-03
 1.0233E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -1.8706E-03  1.2151E-02 -4.5398E-04  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -3.4933E-03
 1.3936E-02 -4.8922E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00 -2.8150E-07 -4.6915E-03  1.3492E-02

 Central Guide Tube
 7.9644E-04  9.5728E-06  4.9135E-05  5.7367E-04  3.7923E-03  1.3911E-02
 3.2553E-02  7.1769E-02  1.2043E-08  1.2158E-08  1.5436E-08  9.9823E-08
 3.9657E-07  3.6725E-07  1.5728E-06  3.7642E-06  2.8708E+00  2.5801E+00
 2.4490E+00  2.4338E+00  2.4338E+00  2.4338E+00  2.4338E+00  2.4338E+00
 3.5044E-01  4.1109E-01  2.3814E-01  3.2919E-04  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  6.1586E-02  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  5.0930E-02  1.2243E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.7769E-02  1.2945E-01  5.0663E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.0811E-04  1.2950E-03  1.1458E-01  8.5773E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.2231E-05
 1.5859E-03  2.1587E-01  8.3959E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.7996E-05  5.5866E-03  2.1732E-01  7.1624E-01
 5.7569E-03  0.0000E+00  0.0000E+00  0.0000E+00  2.9381E-06  8.1078E-04
 3.1119E-02  3.4787E-01  9.3701E-01  1.8226E-01  0.0000E+00  0.0000E+00
 0.0000E+00  2.3890E-04  9.4599E-03  7.1113E-02  4.6434E-01  1.9948E+00
 3.5054E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.3104E-02  6.6671E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  9.8816E-03  5.9651E-02
 3.0591E-01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 1.2696E-05  8.4128E-05  5.1021E-02  5.6358E-01  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  9.0195E-05  9.6954E-02
 5.5977E-01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  5.0305E-04  1.0548E-01  4.7648E-01  3.6520E-03  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  1.0903E-05  6.4612E-03  1.2817E-01
 4.9850E-01  3.3104E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 8.4081E-04  5.4002E-03  6.5305E-02  4.9338E-01

Uncontrolled MOX Assembly

Moderator
 8.2775E-04  9.5705E-06  4.8672E-05  5.7121E-04  3.7254E-03  1.3362E-02
 3.0607E-02  7.0891E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  6.1851E-02  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  5.0404E-02  1.2244E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.7498E-02  1.2917E-01  5.0554E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.0503E-04  1.2925E-03  1.1275E-01  8.6403E-01
```

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 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.2193E-05
 1.5605E-03  2.0944E-01  8.4795E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.7325E-05  5.4202E-03  2.1005E-01  7.4494E-01
 9.3870E-03  0.0000E+00  0.0000E+00  0.0000E+00  2.8843E-06  7.8664E-04
 3.0083E-02  3.2046E-01  9.5976E-01  1.8579E-01  0.0000E+00  0.0000E+00
 0.0000E+00  2.3150E-04  9.1453E-03  6.5838E-02  4.0037E-01  1.9732E+00
 3.5237E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.2719E-02  6.6696E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  9.7647E-03  5.9524E-02
 3.0489E-01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 1.2541E-05  8.3913E-05  5.0131E-02  5.6641E-01  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  8.8545E-05  9.3920E-02
 5.6431E-01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  4.8698E-04  1.0107E-01  4.9341E-01  5.9982E-03  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  1.0555E-05  6.1928E-03  1.1483E-01
 5.1030E-01  3.4727E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 8.0493E-04  5.0638E-03  5.1688E-02  4.9270E-01

Zirconium Cladding
 7.3308E-05  4.9487E-04  7.8016E-04  7.5866E-03  2.6317E-04  9.9650E-04
 2.2947E-03  5.3310E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  1.1828E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  3.4637E-02  2.2848E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.0451E-02  1.5866E-02  3.8580E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  9.7083E-04  3.7073E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  1.1687E-03  2.6967E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.4632E-03  2.6973E-01
 3.8844E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  4.3632E-03  2.6111E-01  9.8676E-03  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  9.4492E-03  2.6601E-01
 5.3524E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -4.5510E-04  7.9852E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -1.6232E-05 -7.3279E-04
 4.6500E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -2.4744E-04  3.1274E-03  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -3.8517E-04
 2.4792E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -4.8050E-04  3.3859E-03 -4.7561E-04  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -1.0237E-03
 4.8062E-03 -1.7761E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -1.8063E-03  4.1666E-03

MOX 4.3% TRU Fuel
 1.5228E-02  8.8018E-03  6.5059E-03  3.8989E-02  1.6320E-01  2.3265E-01
 8.6981E-01  7.3095E-01  1.4228E-02  6.8715E-03  1.2994E-03  6.1017E-03
 3.7651E-02  1.9017E-02  4.9152E-01  4.1952E-01  2.9521E+00  2.7334E+00
 2.8962E+00  2.8560E+00  2.8628E+00  2.8549E+00  2.8634E+00  2.8686E+00
 3.6834E-01  4.0323E-01  2.2809E-01  3.3046E-04  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  1.7447E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  3.5606E-02  2.3754E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.2208E-02  5.8522E-02  4.2372E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  8.2577E-06  1.4485E-05  2.9147E-03  5.0687E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  4.9249E-03  4.6417E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  5.7611E-03  3.9395E-01
 9.9594E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  1.2602E-02  3.6511E-01  2.8613E-02  0.0000E+00  0.0000E+00
```

```
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  2.1323E-02  3.7472E-01
 9.7228E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -3.9159E-04  7.3360E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  2.8625E-04 -1.0779E-02
 4.9320E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 5.1331E-07  0.0000E+00 -8.9287E-04  9.9022E-03  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -1.5171E-03
 1.0165E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -1.7795E-03  1.1422E-02 -8.1835E-04  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -2.7442E-03
 1.2958E-02 -4.7936E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00 -2.4783E-07 -3.3227E-03  1.3371E-02

MOX 7.0% TRU Fuel
 1.6283E-02  9.8880E-03  7.4059E-03  4.5838E-02  2.0081E-01  3.1355E-01
 1.3020E+00  1.1186E+00  1.5284E-02  7.9316E-03  2.0210E-03  9.3575E-03
 5.6374E-02  2.9041E-02  7.3714E-01  6.5425E-01  2.9845E+00  2.7781E+00
 2.9075E+00  2.8687E+00  2.8711E+00  2.8671E+00  2.8654E+00  2.8752E+00
 3.6880E-01  4.0316E-01  2.2771E-01  3.2969E-04  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  1.7729E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  3.5911E-02  2.4012E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.2629E-02  5.8916E-02  4.2917E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  8.6631E-06  1.4899E-05  2.9215E-03  5.1708E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  4.9304E-03  4.7387E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  5.7824E-03  4.0598E-01
 1.0786E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  1.2386E-02  3.6926E-01  2.8882E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  2.1320E-02  3.7806E-01
 9.9289E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -3.8402E-04  7.4668E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  2.8673E-04 -1.0737E-02
 5.0431E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 5.1532E-07  0.0000E+00 -8.9220E-04  9.9505E-03  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -1.5192E-03
 1.0205E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -1.7925E-03  1.1391E-02 -8.8178E-04  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -2.6731E-03
 1.2975E-02 -4.8474E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00 -2.4413E-07 -3.2508E-03  1.3452E-02

MOX 8.7% TRU Fuel
 1.6985E-02  1.0613E-02  7.9976E-03  5.0053E-02  2.2179E-01  3.5416E-01
 1.5528E+00  1.3715E+00  1.5988E-02  8.6394E-03  2.5011E-03  1.1484E-02
 6.7807E-02  3.5277E-02  8.7755E-01  8.0897E-01  3.0038E+00  2.8018E+00
 2.9115E+00  2.8733E+00  2.8745E+00  2.8717E+00  2.8661E+00  2.8776E+00
 3.6892E-01  4.0313E-01  2.2762E-01  3.2954E-04  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  1.7917E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  3.6112E-02  2.4182E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.2910E-02  5.9170E-02  4.3271E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  8.9377E-06  1.5170E-05  2.9168E-03  5.2306E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  4.9200E-03  4.7940E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  5.7545E-03  4.1333E-01
 1.1619E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  1.1945E-02  3.7264E-01  2.9236E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  2.0474E-02  3.8012E-01
 1.0066E-01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -3.7883E-04  7.5536E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  2.8702E-04 -1.0703E-02
 5.1222E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
```

```
 5.1698E-07  0.0000E+00 -8.8899E-04  9.9755E-03  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -1.5162E-03
 1.0218E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00 -1.7899E-03  1.1300E-02 -9.4378E-04  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 -2.5620E-03
 1.2906E-02 -4.8973E-03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00 -2.3588E-07 -3.1017E-03  1.3520E-02

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 8.3130E-04  9.5870E-06  4.9105E-05  5.7201E-04  3.7409E-03  1.3472E-02
 3.1044E-02  7.2043E-02  1.2052E-08  1.2160E-08  1.5432E-08  9.9528E-08
 3.9680E-07  3.3658E-07  1.4719E-06  3.7814E-06  2.8776E+00  2.5803E+00
 2.4491E+00  2.4338E+00  2.4338E+00  2.4338E+00  2.4338E+00  2.4338E+00
 3.5044E-01  4.1109E-01  2.3814E-01  3.2919E-04  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  6.1865E-02  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  5.0368E-02  1.2246E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2.7479E-02  1.2912E-01  5.0663E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.0481E-04  1.2922E-03  1.1443E-01  8.5863E-01
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.2186E-05
 1.5838E-03  2.1491E-01  8.4598E-01  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.7937E-05  5.5618E-03  2.1189E-01  7.3959E-01
 8.3525E-03  0.0000E+00  0.0000E+00  0.0000E+00  2.9332E-06  8.0718E-04
 3.0354E-02  3.2570E-01  9.5613E-01  1.8297E-01  0.0000E+00  0.0000E+00
 0.0000E+00  2.3773E-04  9.2274E-03  6.6890E-02  4.1364E-01  1.9995E+00
 3.5250E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  3.2692E-02  6.6717E-02  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  9.7564E-03  5.9505E-02
 3.0588E-01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 1.2528E-05  8.3875E-05  5.0943E-02  5.6400E-01  0.0000E+00  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  9.0046E-05  9.6472E-02
 5.6333E-01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 0.0000E+00  5.0043E-04  1.0212E-01  4.9029E-01  5.3282E-03  0.0000E+00
 0.0000E+00  0.0000E+00  0.0000E+00  1.0847E-05  6.2559E-03  1.1734E-01
 5.0844E-01  3.3439E-02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 8.1346E-04  5.1277E-03  5.4261E-02  4.9262E-01
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REFERENCES

[1] M. A. SMITH, E.E. LEWIS, B. NA, "Benchmark on Deterministic Transport Calculations Without Spatial Homogenization: MOX Fuel Assembly 3-D Extension Case," OECD/NEA report NEA/NSC/DOC(2005)16.

[2] S. CATHALAU, J.C. LEFEBVRE, J.P. WEST, "Proposal for a Second Stage of the Benchmark on Power Distributions within Assemblies," NEA/NSC/DOC(96)2.

[3] T. KOZLOWSKI and T. J. DOWNAR, "OECD/NEA and U.S. NRC PWR MOX/UO2 Core Transient Benchmark," NEA/NSC/DOC(2003)20, August 2003.

[4] Z. ZHANG, F. RAHNEMA, D. ZHANG, J. M. POUNDERS, A. M. OUGOUAG, "Simplified two and three dimensional HTTR benchmark problems," *Annals of Nuclear Energy*, **38**, 1172 (2011).

[5] S. DOUGLASS, F. RAHNEMA, J. MARGULIES, "A stylized three dimensional PWR whole-core benchmark problem with Gadolinium," *Annals of Nuclear Energy*, **37**, 1384 (2010).

[6] J.M. POUNDERS, F. RAHNEMA, D. SERGHIUTA, J. THOLAMMAKKIL, "A 3D stylized half-core CANDU benchmark problem," *Annals of Nuclear Energy*, **38**, 876 (2011).

[7] J.E. HOOGENBOOM, W. R. MARTIN and B. PETROVIC, "Monte Carlo Performance Benchmark for Detailed Power Density Calculation in a Full Size Reactor Core," Benchmark Specifications Revision 1.2, July 2011, http://www.nea.fr/dbprog/MonteCarloPerformanceBenchmark.htm (2010).

[8] T. SIMEONOV, "Release Notes – Helios System Version 1.8," Studsvik Scandpower Report, SSP-03/221, November 26 (2003).

[9] F.B. BROWN, et al., "MCNP Version 5," *Trans. Am. Nucl. Soc.*, **87**, pp. 273-276 (November, 2002).

[10] R.J. NATH, Ed., PWR Technology Manual, WCAP-7730, PWR Systems Division, Westinghouse Nuclear Energy Systems. (1971).

[11] B. ROQUE, P. MARIMBEAU, J.P. GROUILLER, “Specification for the Phase 1 of a Depletion Calculation Benchmark Devoted to Fuel Cycles,” NEA/NSC/DOC (2004).